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Mechanical and Rheological Properties of Australian Wheats. Part 1 - Effect of variety on Load-Deformation Characteristics

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WOLLONGONG UNIVERSITY COLLEGE
THE UNIVERSITY OF NEW SOUTH WALES

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MECHANICAL AND RHEOLOGICAL PROPERTIES OF AUSTRALIAN WHEATS

PART I - EFFECT OF VARIETY ON LOAD-DEFORMATION CHARACTERISTICS.

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SUMMARY

This Bulletin presents the results of an experimental programme to determine the load-deformation characteristics of several Australian wheat varieties at normal moisture contents. The grains have been compressed at a constant loading rate, in two loading positions, lying flat and on edge; the resulting load deformation curves have shown that two points are of particular interest, the proportional limit load and the maximum or fracture load. The concept of load index, which is defined as the ratio of load to specific deformation, is introduced. It is shown that both load and load index are linearly correlated to Symes' Particle Size Index for each loading position and for both the proportional limit and maximum loads.

ACKNOWLEDGEMENTS

The work presented in this report is part of a project dealing with bulk handling of grain which is in progress at Wollongong University College. Financial support has been received from the Commonwealth Wheat Industry Research Council and Commonwealth Rural Credits Development Fund.

Grateful acknowledgement is made to the officers of the N.S.W. Department of Agriculture who have made valuable contributions to the work. In particular, thanks are due to Mr. J. G. Drever, Agricultural Engineer, Mr. E. H. Jacob and Mr. G. Almgren of the Division of Science Services, and Mr. K. J. Symes of Wagga Agricultural College.

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SECTION 1

INTRODUCTION AND SURVEY OF THE LITERATURE

Modern developments towards increased mechanization in the methods of growing, handling and processing agricultural products, have highlighted the importance of gaining a better understanding of the physical and mechanical properties of the materials involved. Researchers (1,2)* have emphasised the need for research into the physical properties of bulk handled agricultural materials and a general coverage of the literature is presented in Appendix 3.

As far as the wheat grain and its mechanical properties are concerned, the initial research related to the measurement of its "hardness", a term which Katz et.al. (3) reported as being widely used to describe those properties of grains which are of interest to wheat breeders and millers. A number of attempts have been made to measure either the hardness of individual grains or the average hardness of a collection of grains. Generally these methods can be divided into the following groups :-

(a) The internal texture of the grain.

A visual assessment of the vitreous versus mealy areas of a cut kernel was made by Swanson (4); the grain was classified as either vitreous, semi-vitreous or mealy.

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* Numbers in parenthesis refer to the bibliography.

(b) Indentation Methods.

Generally these methods have used modifications of micro-hardness testers developed for the study of hardness in metals. Several workers (5,6), used the Miag Micro-hardness Tester which is an apparatus similar in conception to the Vickers Hardness Tester. The size of the indentation provides a relative measure of the hardness of the material. Katz et.al. (3) modified a Barc l Impressor to make it suitable for the hardness testing of wheat grain sections. Hardness is measured by the distance the spring loaded stylus is displaced into its surrounding casing when pressed against a test object. One model has been produced which is capable of 30 or more independent hardness measurements on a single grain cross section.

(c) Grinding and Crushing Methods.

Several methods of hardness measurement have been evolved which either grind or crush the samples.

The Brabender hardness tester, which consists essentially of a small burr mill fitted to the dynamometer coupling of the Farinograph has been used by Paukner (7) on barley and Milner and Shell nberger (8) on wheat. This device measures the torque required to drive the mill as a small sample of grain is ground. The data is expressed as the energy required per milled gram of grain.

Bennett (9) devised a machine which crushed the grain between an inner and outer crushing wheel. The force involved in crushing the grain is sensed as a pressure change in an hydraulic cylinder; this pressure change, which is indicated on a gauge, actuates a mechanical integrating device and counter. As the force required to crush the grain increases, the number recorded on the counter also increases. Either the counter number or the pressure gauge reading can be used as an index of hardness. The machine was tested principally with corn; tests made on wheat without changing the clearances from those used on corn were not satisfactory. However, it is claimed that with appropriate adjustments it is possible that wheat also could be tested accurately.

A traditional method for measuring the average hardness of a sample of grain is the laboratory-scale barley pearler. This test was developed for the determination of kernel hardness in wheat by Taylor et.al. (10). Essentially it consists of placing a weighed amount of grain in a barley pearler which is merely a grinding wheel running in a closed case. After the machine has been run for a definite length of time, the pearled grain is removed and weighed. It has been found that the harder the grain the less the amount of material removed during pearling. The test is rapid, accurate and requires only a small sample. McCluggage (11) investigated some of the factors influencing the pearling test for the determination of kernel hardness in wheat and suggested a standard procedure to be followed when performing the test. This method of hardness determination has also been used by several other workers (12,13).

The granularity of the whole meal produced when a sample of grain is ground has also been used as an index of hardness. In Australia this work was pioneered by Symes (14) who describes fully the work of earlier researchers (15 - 24) who used similar techniques. The current method for determining Symes' particle size index is described in a recent paper (25); since extensive use is made of his results in this present work, the method is reproduced in Appendix 5.

(d) Grain loading techniques.

In 1910 Roberts (26) reported the development of a testing machine in which the wheat kernel was crushed by weighing an arm with an increasing load. The weight required to crush the grain was taken as an index of grain hardness. The test was modified in Russia and other European countries by redesigning the equipment (27) so that several grains could be tested at once.

One of the most extensive investigations of the mechanical properties of wheat grains is that reported by Shpolyanskaya (28). She studied the mechanical properties of whole grains by modifying a laboratory impact tester to make it suitable for compression tests with static and variable rate loading. The load-deformation characteristics for two varieties, Gordeiform 10 and Lyntestsens 62, are presented, together with a method of determining the modulus of elasticity of a wheat grain which employs the Hertz stress analysis and an estimated value of Poisson's ratio.

Work on the single wheat grain was also performed by Zoerb (29). He developed a compression testing machine which enabled the grain to be loaded at three different loading rates (0.0777 in./min, 0.2666 in./min, 0.4667 in./min.). The modulus of elasticity was determined from load-deformation tests on grain cores. Tests were performed over a range of moisture contents (16.1 to 27.4% d.b.) and it is shown that moisture content has the greatest influence on the strength properties of the grain.

Bilanski (30) tested five common grains (including wheat) under three different loading conditions and at various moisture contents ranging from 1 to 18% (measured with a Brown-Duval moisture tester). The three loading conditions closely simulate those to which grains are subjected during actual harvesting; these loading conditions were :

(i) low-velocity loading, obtained by applying a load gradually;

(ii) medium velocity loading, obtained by striking the grain with a pendulum; and

(iii) high-velocity loading, obtained by dropping the grain into the path of a rotating paddle wheel.

For wheat, it is shown that moisture content and grain position both influence its breaking strength.

The resistance to damage by impact of two wheat varieties (Koga 11 and Cappelle Desprez) has been investigated by Mitchell and Rounthwaite (31). Their results show that whereas Koga 11

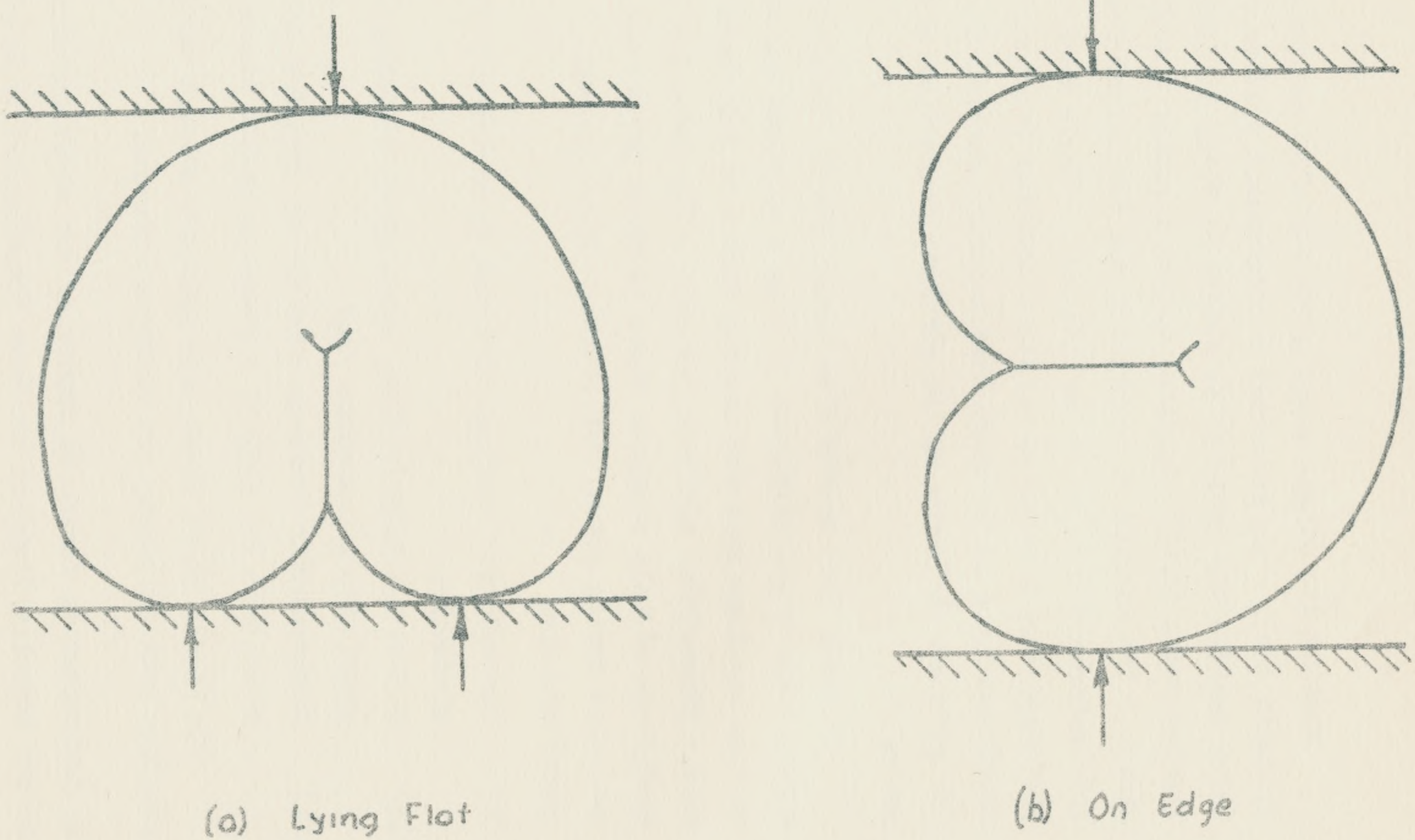


FIG 1 - LOADING POSITIONS FOR INDIVIDUAL WHEAT GRAINS is more resistant to breakage than Cappelle Desprez, it is at the lower levels of moisture that breakage is highest and at the higher levels that germination is most adversely affected.

Shpolyanskaya's (28) application of the Hertz stress analysis to the determination of modulus of elasticity of wheat grains has been refined by Arnold and Roberts (32). Shpolyanskaya made three principal simplifications : firstly, the grain is considered as a sphere of diameter equal to the grain width; secondly, for a grain loaded as shown in Fig. 1 (a), the local deformation for contact with the lower plate is considered negligibly small and the total deformation of the grain is taken to be equal to the deformation at the upper plate; thirdly, Poisson's ratio for wheat is taken to be 0.3. Arnold and Roberts considered the latter simplification reasonable but regarded the first two as invalid even for approximation purposes. It is shown that the modulus of elasticity determined on the basis of Shpolyanskaya's simplifications is substantially different from that obtained from a more rigorous analysis which takes the actual grain shape and both top and bottom localized deformations into account.

The work reported in this Bulletin is part of an investigation of the mechanical and rheological properties of some granular materials. It is shown that the load-deformation characteristics of wheat grains are influenced significantly by varietal differences. All the testing work has been carried out at one rate of loading and over a narrow band of moisture contents. The effects of these two variables is presently being investigated and will be reported separately.

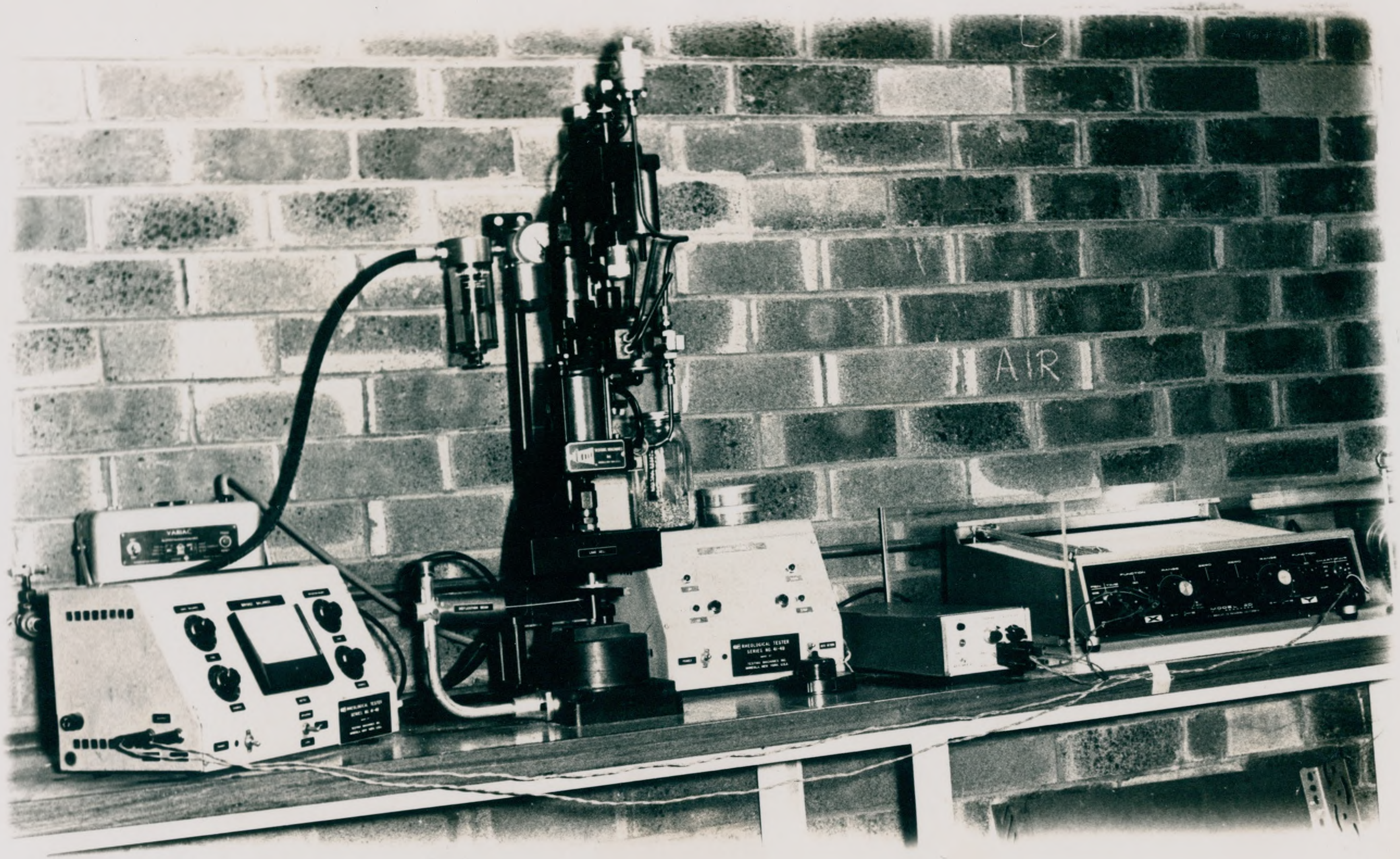


FIG 2 RHEOLOGICAL TESTING MACHINE

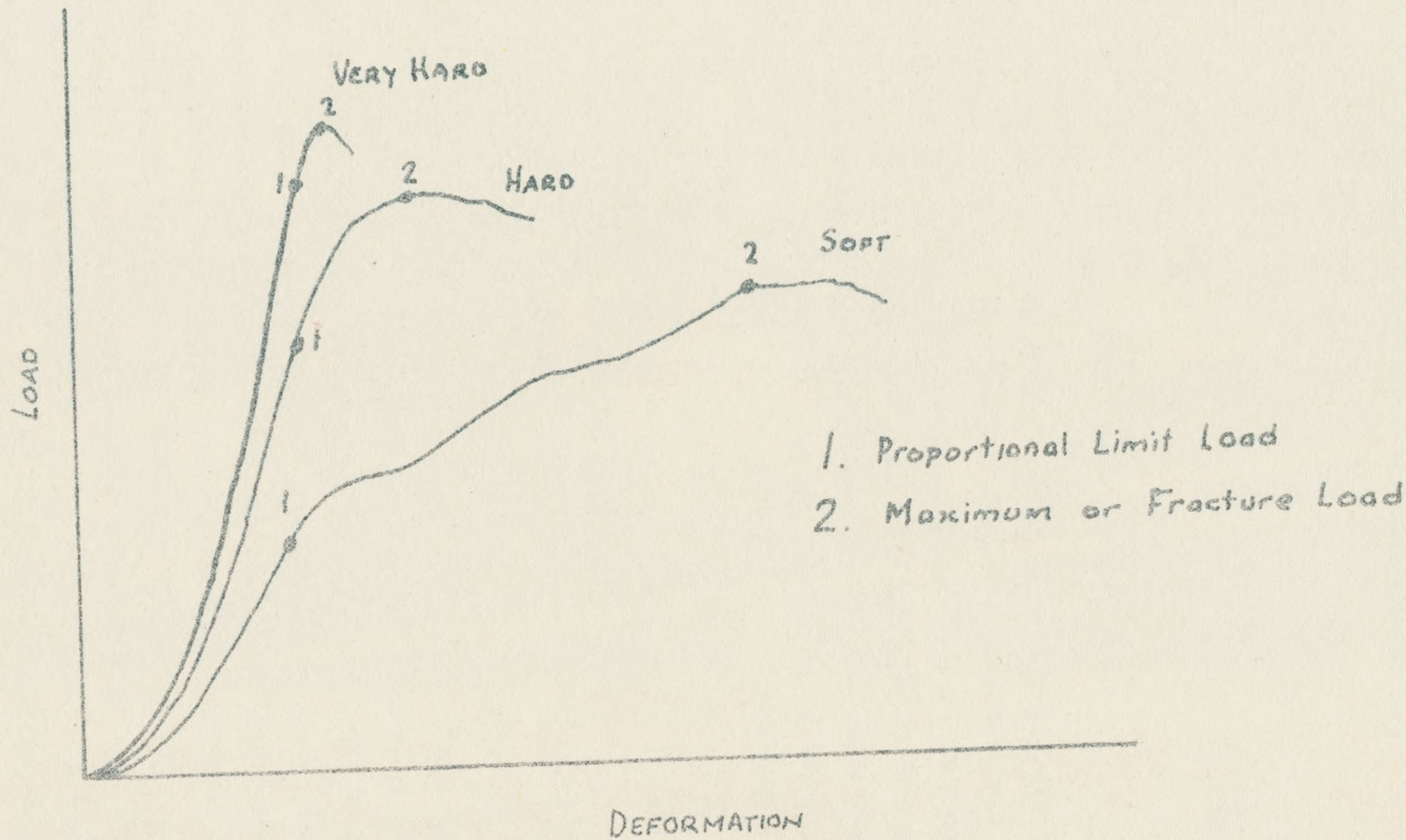
SECTION 2

EXPERIMENTAL PROGRAMME

The initial phase of an experimental programme, to evaluate the load-deformation characteristics of individual grains of various wheat varieties, has been completed. The work has been performed using a testing machine of the type developed by Mohsenin (33). A photograph of this machine and associated components is shown in Fig. 2. Essentially there are three basic components :

(i) the loading apparatus;
(ii) the load and deformation sensing elements and associated electronic instrumentation; and
(iii) the recording instrument.

The loading apparatus consists of a $2\frac{1}{2}$ in. dia. x 2 in. stroke double acting air cylinder with adjustable hydraulic valves to control the ram velocity in both directions. The speed of the ram and hence the rate of loading, is continuously variable from zero to almost 50 in./min. The load applied to the grain and the resulting grain deformation are measured using electric resistance strain gauges fixed to deflecting beams. The change in resistance of the strain gauges which is proportional to the change in beam load and deflection, is detected by a special measuring bridge. The output of the measuring bridge for the load beam is fed to the Y terminals of the Moseley type 2D X-Y recorder, while the measuring bridge output for the deflection beam is fed to the X terminals of


VERY HARD
HARD
SOFT
LOAD
DEFORMATION
1
2
1
2
1
2
1. Proportional Limit Load
2. Maximum or Fracture Load

the recorder via a Dymec model 2460 A D.C. amplifier. The Dymec amplifier has a maximum amplification of 1,000 X and is used to improve the deflection beam signal for wheat testing.

Experimental testing of individual grains of various varieties of Australian wheats commenced with samples from the 1964/65 harvest obtained from the Division of Science Services, N.S.W. Department of Agriculture. Further samples from the 1965/66 harvest were obtained from the Temora Agricultural Research Station and tested. Details of all the samples are given in Tables 1 and 2*. Some breeding and other information on most of the varieties tested is given in Appendix 4.

Load-deformation tests were performed for the two loading configurations "lying flat" and "on edge", as illustrated in Fig. 1. The moisture content range of the grain was 11 to 13% (as measured with a Marconi moisture meter) and the loading rate approximately 0.26 in./min. This speed was chosen as it approximates to Zoerb's (29) medium testing speed of 0.2666 in./min. Typical load deformation graphs are shown in Fig.3.

Two points on these graphs which are considered to be of particular significance, are the proportional limit load and the maximum or fracture load. These points are indicated on Fig.3. The values of the load and the ratio of load to specific deformation at both these points have been determined. In general, each test has been repeated 10 times. All the results have been processed on the IBM 1620 60K computer at the College. These results are summarised in Tables 3 and 4 and a typical

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*Tables and graphs are given in Appendix 1.

computer output, showing the details for one variety, given in Appendix 6.

To allow the variation of load and load index with variety to be assessed, these values have been plotted using Symes' Particle Size Index for each variety as the "independent" variable. The values of Symes' P.S.I. (34) for each variety is given in Table 4*. Regression equations, together with a test for correlation and an analysis of variance test for linearity (35, 36, 37) have been calculated using the computer. These results are summarised in Tables 5 and 6 and the equations plotted in graphs 1 to 24.

Values of the Pearling Index were determined for the 1965/66 samples by grinding 10 gm. samples in a Strong-Scott Barley Pearler for one minute. These figures are given in Table 7. Linear regression equations of load index and load on pearling index, together with tests for correlation and linearity have been calculated. These results have been summarised in Tables 8 and 9 and the equations plotted in Graphs 25 and 26.

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* It will be noted that several samples of Mendos and Olympic A103 are included in Tables 1 and 2 but as Symes' P.S.I. has not been determined for these varieties, they have been omitted from the present analysis.

SECTION 3.

DISCUSSION OF RESULTS

Inspection of Graphs 1 to 24 reveals that both load and load index vary significantly with Symes' particle size index, and hence with variety for both the proportional limit load and maximum load, and for both loading positions. Reference to Tables of Student's T shows that the linear correlation coefficients presented are significant at the 0.1% level in 96% of all cases.

However, the analysis of variance test for linearity shows that only for the case of load index versus Symes' P.S.I. for the flat position and proportional limit load with Dural omitted, does the linear regression equation provide a significant measure of the relationship between the variables plotted. Fitting of higher order polynomials (up to the fifth degree) to the data was performed but rejected when the overall improvement was only slight. The value of Symes' index for some varieties has only been determined once while others have been determined up to seven times. In order to see if the number of determinations had any effect on the results, regression equations were calculated.for those varieties for which Symes' index has been determined five times or more. In some cases a slight improvement resulted while in others a less acceptable result was obtained. Similar significant results were obtained from the regression analysis of load index and load versus pearling index.

It is felt that the edge position is less reliable than the flat position due to the difficulty of maintaining the correct orientation when loading the grain; the grain frequently slips when the load is being applied. The fact that, in this position, the plane of the crease is perpendicular to the direction of loading must have some influence on the deformation characteristics and hence on the load index value of the grain. For the flat position the main difficulty encountered was the tendency of some varieties, for example, Gabo to roll slightly when the load is first applied. However, this characteristic generally exhibits itself in the load-deformation curve and, to a large degree, can be allowed for when selecting the origin. It is expected that the results for the maximum load point should be less reliable than the proportional limit point especially for the softer wheats since, in many cases, it is not clear-cut from the curve the point at which the grain failed. For the harder wheats the grain simply shatters but as the grains become softer they tend to be squashed flat rather than break up.

Zoerb (29) observed that the load a grain can sustain in the edge position is substantially the same as the load it can sustain in the flat position. On the basis of the results presented in this bulletin it is evident that this observation needs some qualification when applied to Australian wheat varieties. Inspection of the load versus Symes' index regression lines shows that the proportional limit loads for the flat and edge position are roughly the same but, in general, the maximum loads for the edge position are significantly greater than they are for the flat position. On the other hand, the overall results for load index indicate that the flat and edge positions produce similar results.

Comparison of the results obtained with the 1964/65 harvest samples with those for the 1965/66 harvest reveals that, in general, the load and load index results for the latter group are less than those for the former. This would indicate that the area where the varieties are grown has a significant influence; the 1964/65 samples were from the northern areas of the State while the 1965/66 were from southern areas. This inference is substantiated further when the 1965/66 samples are examined more closely. The twenty samples came from four different groups, three of which were grown at Temora and one at Moombooldool, 60 miles west of Temora. The soil type on Temora is a red-brown earth of clayey-loam texture while Moombooldool is on sandy mallee country. Examination of Graphs 27 to 31 shows that both load index and pearling index gave reasonably similar results for the Temora plots, but the Moombooldool plot gave significantly lower values.

It is interesting to note the results obtained for the graphs of load and load index versus Symes' index for the 1964/65 varieties 200 to 206, which were all grown in the one trial. The F ratios obtained from the linearity test indicate linear relationships which are significant for all the variations considered. It is hoped to obtain further single trial samples of varieties representing a wide range of Symes' index values to see if the assumption of a linear relationship between load and Symes' index, and load index and Symes' index is still valid; other influences such as soil type, ground preparation, sowing time, weather conditions, are held constant.

The concept of load index is useful when considering the ability of a particular wheat variety to resist mechanical damage. Grain damage can be caused in several ways, but as far as mechanical handling equipment is concerned, damage is caused either by an applied force as, for example, in the beater drum of a harvester, or by an applied deformation as, for example, when a grain is forced through the fixed clearances of an auger with bearings at each end of the flight. Grains with a high load index (hard grains) generally can resist higher loads but lesser deformations than grains with a low grain index (soft grains). Thus taking the two bearing auger as an example again, soft grains should be damaged less than hard grains, provided the clearances are not such that the deformations involved induce loads greater than the grain fracture load. At the moment this is only a conjecture, but it is hoped in the future to be able to verify it by experiment.

SECTION 4

CONCLUSIONS

The load deformation testing of individual wheat grains has shown that the values of load and load index vary significantly with variety. This is true for both flat and edge loading positions and for both the proportional limit and maximum load points. The most consistent results were obtained for the flat position and proportional limit load. The edge position gave a wider scatter of results largely because of the variations in the grain crease width; in addition some difficulty was encountered with regard to holding the grains in this position for the load testing.

The linear regression equations presented show that load and load index vary ~~inversely~~ directly with Symes' particle size index and directly with pearling index; the harder varieties sustaining the greater loads and having the larger load index values.

The results also indicate that the load and load index characteristics of a particular wheat variety are dependent on the locality in which the grain is grown.

SECTION 5. APPENDICES

APPENDIX 1. TABLES AND GRAPHS

TABLE 1 - SAMPLES TESTED FROM 1964/65 HARVEST

Sample Number	Variety	Bushell Wt.-lb.	Protein %	1000 gr. Wt.-gm	Remarks
187	Dural	$66\frac{1}{4}$	13.2	39.9	Grown Tamworth Agric. Res. Station.
199	Mendos	66	9.8	39.1	Grown, F.V.T. B. Donaldson Dunedoo
200	Mengavi	66	9.8	38.7	
201	Gabo	$65\frac{1}{4}$	9.0	37.5	
202	Gamenya	$66\frac{1}{4}$	8.6	38.0	
204	Gala	67	9.9	36.4	
205	Spica	$67\frac{3}{4}$	10.1	38.1	
206	Pinnacle	$61\frac{3}{4}$	10.4	34.9	
285	Festiguay	$66\frac{1}{4}$	9.2	34.9	Grown, F.V.T. R. Doran Pockataroo
286	Mendos	$64\frac{1}{2}$	9.8	40.2	
288	Gala	$66\frac{1}{4}$	10.6	36.5	
289	Gabo	$64\frac{3}{4}$	9.9	37.0	
291	Spica	$67\frac{3}{4}$	11.1	41.4	
498	Spica	66	12.1	38.0	Grown F.V.T. Reece Bingara
501	Spica	66	12.3	38.0	
504	Spica	66	12.4	38.7	
507	Spica	$65\frac{3}{4}$	12.3	38.4	

TABLE 1 (continued) SAMPLES TESTED FROM 1964/65 HARVEST

Sample Number	Variety	Bushell Wt.-lb.	Protein %	1000 Grain Wt.- gm.	Remarks
561	Chile 1B	$65\frac{3}{4}$	12.4	39.1	Grown Condobolin Agric. Res. Station.
562	Falcon	$66\frac{1}{2}$	12.0	38.8	
563	Festiguay	$66\frac{1}{2}$	12.5	37.1	
564	Glenwari	$65\frac{1}{2}$	10.8	40.1	
565	Heron	$67\frac{3}{4}$	11.3	41.1	
566	Mexico 120	$65\frac{3}{4}$	12.8	36.0	
568	Olympic A103	$66\frac{1}{4}$	9.8	36.7	
746	Festiguay	67	11.9	35.5	Grown F.V.T. K.H.Nut Merriwa
747	Gabo	65	11.0	38.6	
748	Gala	$66\frac{1}{4}$	12.9	31.9	
751	Mendos	66	11.9	42.6	
753	Spica	$67\frac{1}{2}$	11.6	43.0	

These samples were obtained from the Cereals Section, Scientific Services Laboratories, N.S.W. Department of Agriculture.

TABLE 2 - SAMPLES TESTED FROM 1965/66 HARVEST

Sample Number	Variety	Bushell Wt.-lb.	Protein %	1000 gr. Wt. - gm.	Remarks
6501	Gamenya	62¼	15.9	38.4	Pure seed
6502	Falcon	63¼	16.0	41.5	areas -
6503	Heron	61	14.8	42.5	Temora
6504	Mendos	61	17.2	38.5	Agric.Res.
6505	Festiguay	60¾	17.4	35.2	Station
6506	Gamenya	59¾	11.1	36.3	
6507	Falcon	62¼	11.3	39.1	Moombool-
6508	Heron	62¼	10.8	40.0	dool
6509	Olympic A103	61¾	10.9	37.6	Trial
6510	Pinnacle	64¾	14.5	46.6	
6511	Festiguay	63½	17.5	37.3	Late
6512	Heron	65	15.2	41.0	Maturing
6513	Windebri	64¾	15.8	38.6	1/40th
6514	Bordan	63¼	16.1	47.3	Acre
6515	Glenwari	63	14.6	46.7	Trial
6516	Olympic A103	65½	14.5	37.6	Temora
6517	Gamenya	60	14.6	40.0	Early Mid-
6518	Falcon	62	14.3	41.8	Maturing
6519	Heron	63	13.9	43.4	1/40th Acre
6520	Olympic A103	62½	13.2	39.2	Trial- Temora

These samples were obtained from the Temora Agricultural Research Station, N.S.W. Dept. of Agriculture.

TABLE 3. - SUMMARY OF LOAD AND LOAD INDEX VALUES FOR INDIVIDUAL SAMPLES

SAMPLE AND MOIST. CONT.	LOADING POSITION	NO. OF READINGS	LOAD lb.	STD. DEV. %	LOAD INDEX lb.	STD DEV. %
187	F. - P.L.L.	18	33.3	25.6	690	16.5
DURAL	F. - M.L.	17	40.5	21.5	570	21.7
13%	E. - P.L.L.	10	22.9	23.6	644	18.2
	E. - M.L.	10	43.5	20.6	560	17.5
199	F. - P.L.L.	17	16.4	22.4	405	21.9
MENDOS	F. - M.L.	17	24.7	27.2	344	22.5
12.5%	E. - P.L.L.	12	14.5	20.3	482	28.9
	E. - M.L.	12	18.9	14.4	423	25.6
200	F. - P.L.L.	15	14.1	26.6	346	16.7
MENGAVI	F. - M.L.	15	21.6	29.8	299	22.1
12.5%	E. - P.L.L.	10	13.6	14.9	361	31.3
	E. - M.L.	10	18.0	14.0	307	31.6
201	F. - P.L.L.	18	19.4	24.8	401	18.7
GABO	F. - M.L.	17	26.6	17.9	328	21.6
12.5%	E. - P.L.L.	9	18.9	15.6	488	30.1
	E. - M.L.	9	33.5	17.2	334	26.7
202	F. - P.L.L.	18	16.8	31.7	344	22.0
GAMENYA	F. - M.L.	18	21.2	37.7	304	24.1
12.5%	E. - P.L.L.	7	13.5	9.7	324	7.0
	E. - M.L.	7	26.0	16.8	237	16.0
204	F. - P.L.L.	15	19.8	19.2	420	19.7
GALA	F. - M.L.	15	24.1	25.2	357	20.7
12.5%	E. - P.L.L.	9	20.9	15.1	488	40.3
	E. - M.L.	9	32.4	18.4	410	24.1

TABLE 3 (continued) - SUMMARY OF LOAD AND LOAD INDEX VALUES FOR INDIVIDUAL SAMPLES

SAMPLE AND MOIST. CONT.	LOADING POSITION	NO. OF READINGS	LOAD lb.	STD. DEV. %	LOAD INDEX lb.	STD DEV. %
205	F. - P.L.L.	15	15.6	34.3	370	16.7
SPICA	F. - M.L.	15	20.3	27.5	314	13.5
12.5%	E. - P.L.L.	10	15.5	19.1	390	30.5
	E. - M.L.	10	25.9	21.8	327	21.0
206	F. - P.L.L.	10	10.7	20.0	284	13.8
PINNACLE	F. - M.L.	10	19.9	14.8	212	19.8
12.5%	E. - P.L.L.	10	10.4	21.3	306	20.2
	E. - M.L.	10	18.8	22.5	191	24.6
285	F. - P.L.L.	10	17.4	23.8	406	17.7
FESTIGUAY	F. - M.L.	10	22.9	13.8	366	14.9
12.0%	E. - P.L.L.	10	16.9	13.0	428	19.3
	E. - M.L.	10	22.9	9.9	347	13.5
286	F. - P.L.L.	10	16.8	27.7	371	15.0
MENDOS	F. - M.L.	10	28.7	25.8	311	15.7
12.0%	E. - P.L.L.	10	14.6	17.9	444	16.3
	E. - M.L.	10	19.9	11.3	356	20.1
288	F. - P.L.L.	9	14.0	22.4	365	24.8
GALA	F. - M.L.	9	20.8	16.1	294	27.4
11%	E. - P.L.L.	10	18.7	13.6	452	9.9
	E. - M.L.	10	29.2	10.8	340	17.3
289	F. - P.L.L.	10	16.2	25.2	369	22.4
GABO	F. - M.L.	10	22.6	23.6	330	24.3
11.0%	E. - P.L.L.	10	20.3	24.0	494	23.4
	E. - M.L.	10	27.5	20.8	407	22.4

TABLE 3. (continued) - SUMMARY OF LOAD AND LOAD INDEX VALUES FOR INDIVIDUAL SAMPLES

SAMPLE AND MOIST. CONT.	LOADING POSITION	NO. OF READINGS	LOAD lb.	STD. DEV. %	LOAD INDEX lb.	STD DEV. %
291	F. - P.L.L.	10	10.1	29.1	335	22.1
SPICA	F. - M.L.	10	13.7	26.2	276	19.4
11.5%	E. - P.L.L.	10	17.2	15.1	419	16.0
	E. - M.L.	10	26.4	22.7	340	16.0
498	F. - P.L.L.	15	13.5	18.2	357	16.9
SPICA	F. - M.L.	15	18.1	26.0	312	18.1
11.5%	E. - P.L.L.	9	15.8	20.2	420	24.4
	E. - M.L.	9	26.7	21.7	337	24.2
501	F. - P.L.L.	13	15.1	28.4	412	20.6
SPICA	F. - M.L.	13	19.7	27.0	346	22.0
11.5%	E. - P.L.L.	10	17.9	9.4	479	21.4
	E. - M.L.	10	29.2	13.0	401	19.4
504	F. - P.L.L.	15	14.9	28.7	406	23.7
SPICA	F. - M.L.	15	19.1	18.1	370	26.8
11.5%	E. - P.L.L.	10	17.8	36.2	440	25.3
	E. - M.L.	10	28.9	31.9	379	25.11
507	F. - P.L.L.	14	13.7	22.9	389	20.9
SPICA	F. - M.L.	14	18.1	27.2	346	19.3
11.5%	E. - P.L.L.	10	18.6	21.2	467	15.1
	E. - M.L.	10	29.4	18.5	418	19.4
561	F. - P.L.L.	14	13.7	16.4	351	25.1
CHILE 1B	F. - M.L.	14	22.7	23.5	242	26.5
12%	E. - P.L.L.	9	11.3	24.9	284	18.9
	E. - M.L.	9	23.5	15.7	191	24.2

TABLE 3 (continued) - SUMMARY OF LOAD AND LOAD INDEX VALUES FOR INDIVIDUAL SAMPLES.

SAMPLE AND MOIST. CONT.	LOADING POSITION	NO. OF READINGS	LOAD lb.	STD. DEV. %	LOAD INDEX lb.	STD DEV. %
562	F. - P.L.L.	15	19.2	36.9	454	29.9
FALCON	F. - M.L.	15	28.0	25.3	347	20.0
12.5%	E. - P.L.L.	10	16.7	22.7	328	30.7
	E. - M.L.	10	29.3	25.4	252	20.8
563	F. - P.L.L.	15	15.0	28.2	376	16.9
FESTIGUAY	F. - M.L.	15	21.2	27.6	310	15.2
11.5%	E. - P.L.L.	10	15.9	23.9	436	27.2
	E. - M.L.	10	27.0	16.4	316	22.1
564	F. - P.L.L.	14	12.3	22.3	313	15.7
GLENWARI	F. - M.L.	14	18.5	26.0	250	22.7
12.0%	E. - P.L.L.	10	15.1	18.4	438	18.0
	E. - M.L.	10	22.1	22.0	340	31.8
565	F. - P.L.L.	16	14.6	21.9	337	18.9
HERON	F. - M.L.	16	24.0	13.2	255	24.8
11.5%	E. - P.L.L.	9	16.5	7.5	459	14.3
	E. - M.L.	9	29.1	11.9	230	13.4
566	F. - P.L.L.	14	11.1	21.0	273	18.7
MEXICO 120	F. - M.L.	14	17.7	22.7	221	14.6
12.5%	E. - P.L.L.	8	11.2	48.9	268	27.8
	E. - M.L.	8	25.1	20.3	218	33.8
568	F. - P.L.L.	14	9.4	29.3	234	20.4
OLYMPIC A103	F. - M.L.	14	16.1	36.2	156	25.3
	E. - P.L.L.	9	11.0	39.6	305	31.8
12.0%	E. - M.L.	9	20.4	13.8	166	30.9

TABLE 3 (continued) - SUMMARY OF LOAD AND LOAD INDEX VALUES FOR INDIVIDUAL SAMPLES.

SAMPLE AND MOIST. CONT.	LOADING POSITION	NO. OF READINGS	LOAD lb.	STD. DEV. %	LOAD INDEX lb.	STD DEV. %
746	F. - P.L.L.	10	19.8	19.3	443	13.2
FESTIGUAY	F. - M.L.	10	28.6	16.7	387	9.0
12.0%	E. - P.L.L.	10	21.4	15.4	478	22.7
	E. - M.L.	10	27.2	14.1	449	20.2
747	F. - P.L.L.	10	27.1	20.2	573	15.4
GABO	F. - M.L.	10	37.5	29.7	518	16.4
12.0%	E. - P.L.L.	10	20.4	14.2	518	14.7
	E. - M.L.	10	30.0	9.8	397	9.5
748	F. - P.L.L.	10	24.9	29.4	467	21.5
GALA	F. - M.L.	10	30.8	14.2	410	17.4
11.0%	E. - P.L.L.	10	22.1	13.0	533	18.8
	E. - M.L.	10	32.1	23.6	418	20.9
751	F. - P.L.L.	9	23.4	29.0	501	29.0
MENDOS	F. - M.L.	9	32.8	21.7	400	18.9
12.0%	E. - P.L.L.	10	15.7	15.7	439	25.6
	E. - M.L.	10	22.1	16.2	333	24.8
753	F. - P.L.L.	10	15.2	43.6	446	37.0
SPICA	F. - M.L.	10	18.9	35.9	397	39.2
11.5%	E. - P.L.L.	9	18.6	15.2	462	16.6
	E. - M.L.	9	30.1	14.8	360	19.8

TABLE 3 (continued) - SUMMARY OF LOAD AND LOAD INDEX VALUES FOR INDIVIDUAL SAMPLES.

SAMPLE AND MOIST. CONT.	LOADING POSITION	NO. OF READINGS	LOAD lb.	STD. DEV. %	LOAD INDEX lb.	STD DEV. %
6501	F. - P.L.L.	10	15.0	27.1	368	23.1
GAMENYA	F. - M.L.	10	22.6	26.3	279	27.1
12.5%	E. - P.L.L.	9	13.9	42.0	320	27.0
	E. - M.L.	9	23.0	15.5	234	31.5
6502	F. - P.L.L.	10	21.3	25.9	486	24.6
FALCON	F. - M.L.	10	29.8	21.4	385	24.7
12.0%	E. - P.L.L.	7	18.8	12.0	451	16.2
	E. - M.L.	7	34.1	8.8	330	11.9
6503	F. - P.L.L.	10	9.6	14.6	326	14.4
HERON	F. - M.L.	10	21.7	20.9	188	17.5
12.0%	E. - P.L.L.	10	9.3	15.8	249	17.4
	E. - M.L.	10	20.1	14.5	158	21.5
6504	F. - P.L.L.	10	18.3	19.3	405	22.0
MENDOS	F. - M.L.	10	26.0	16.7	323	25.1
12.5%	E. - P.L.L.	10	16.8	17.7	374	24.0
	E. - M.L.	10	23.6	13.4	292	23.0
6505	F. - P.L.L.	10	15.6	30.9	412	16.3
FESTIGUAY	F. - M.L.	10	19.2	26.4	307	22.0
12.0%	E. - P.L.L.	10	15.0	15.2	326	19.9
	E. - M.L.	10	25.5	21.4	267	9.0
6506	F. - P.L.L.	10	7.5	17.9	203	21.6
GAMENYA	F. - M.L.	10	15.0	18.5	145	20.0
11.5%	E. - P.L.L.	9	9.3	17.1	193	19.7
	E. - M.L.	9	18.0	13.9	142	22.4

TABLE 3 (continued) - SUMMARY OF LOAD AND LOAD INDEX VALUES FOR INDIVIDUAL SAMPLES.

SAMPLE AND MOIST. CONT.	LOADING POSITION	NO. OF READINGS	LOAD lb.	STD. DEV. %	LOAD INDEX lb.	STD DEV. %
6507	F. - P.L.L.	10	11.9	20.8	323	15.5
FALCON	F. - M.L.	10	20.5	18.1	261	17.5
11.5%	E. - P.L.L.	10	16.1	23.8	284	27.1
	E. - M.L.	10	23.6	19.7	235	19.5
6508	F. - P.L.L.	10	8.6	37.3	257	25.9
HERON	F. - M.L.	10	17.4	21.1	154	29.9
11.5%	E. - P.L.L.	10	10.1	24.6	198	13.5
	E. - M.L.	10	17.0	18.5	147	22.6
6509	F. - P.L.L.	10	5.3	25.2	179	23.6
OLYMPIC	F. - M.L.	10	9.4	21.5	116	29.4
A103	E. - P.L.L.	10	7.7	29.3	169	20.0
11.5%	E. - M.L.	10	13.2	17.1	129	16.3
6510	F. - P.L.L.	10	13.7	19.4	315	20.2
PINNACLE	F. - M.L.	10	24.1	22.9	196	16.4
11.5%	E. - P.L.L.	10	12.8	18.8	316	12.3
	E. - M.L.	10	24.3	12.7	183	12.9
6511	F. - P.L.L.	10	17.0	22.7	424	26.6
FESTIGUAY	F. - M.L.	10	23.4	22.7	291	17.1
12.0%	E. - P.L.L.	10	15.9	26.3	385	17.7
	E. - M.L.	10	28.0	21.7	275	17.4
6512	F. - P.L.L.	10	11.4	26.2	323	13.7
HERON	F. - M.L.	10	21.6	10.7	200	17.4
12.0%	E. - P.L.L.	10	12.5	17.3	336	16.7
	E. - M.L.	10	24.5	15.3	202	17.1

TABLE 3 (continued) - SUMMARY OF LOAD AND LOAD INDEX VALUES FOR INDIVIDUAL SAMPLES.

SAMPLE AND MOIST. CONT.	LOADING POSITION	NO. OF READINGS	LOAD lb.	STD. DEV. %	LOAD INDEX lb.	STD. DEV. %
6513 WINDEBRI 12.0%	F. - P.L.L.	10	11.6	25.3	310	17.4
	F. - M.L.	10	18.4	38.5	255	23.5
	E. - P.L.L.	10	16.4	14.2	434	14.2
	E. - M.L.	10	28.1	12.2	282	16.8
6514 BORDAN 12.0%	F. - P.L.L.	10	13.1	37.1	340	25.9
	F. - M.L.	10	19.2	30.2	257	21.8
	E. - P.L.L.	10	14.0	33.2	345	21.7
	E. - M.L.	10	24.8	23.5	227	29.9
6515 GLENWARI 12.0%	F. - P.L.L.	10	11.9	24.4	313	20.4
	F. - M.L.	10	18.9	23.5	234	15.0
	E. - P.L.L.	10	14.9	13.3	371	19.2
	E. - M.L.	10	23.9	15.3	261	14.9
6516 OLYMPIC A103 11.5%	F. - P.L.L.	10	9.5	23.1	242	14.2
	F. - M.L.	10	15.1	25.4	173	19.7
	E. - P.L.L.	10	11.3	29.5	320	17.3
	E. - M.L.	10	20.5	15.4	204	23.1
6517 GAMENYA 11.5%	F. - P.L.L.	10	10.9	34.5	279	23.4
	F. - M.L.	10	17.2	22.9	219	31.1
	E. - P.L.L.	10	10.4	44.9	251	23.9
	E. - M.L.	10	18.0	36.7	178	38.0
6518 FALCON 11.5%	F. - P.L.L.	10	18.4	20.1	426	13.1
	F. - M.L.	10	25.5	14.1	380	15.7
	E. - P.L.L.	10	16.3	25.6	343	30.6
	E. - M.L.	10	26.0	23.7	277	30.4

TABLE 3 (continued) - SUMMARY OF LOAD AND LOAD INDEX VALUES FOR INDIVIDUAL SAMPLES.

SAMPLE AND MOIST. CONT.	LOADING POSITION	NO. OF READINGS	LOAD lb.	STD. DEV. %	LOAD INDEX lb.	STD. DEV. %
6519	F. - P.L.L.	10	9.4	26.4	289	18.1
HERON	F. - M.L.	10	17.2	23.7	188	25.6
11.5%	E. - P.L.L.	10	9.6	24.9	249	20.1
	E. - M.L.	10	21.6	14.7	146	19.5
6520	F. - P.L.L.	10	7.8	23.3	283	16.5
OLYMPIC	F. - M.L.	10	15.6	28.9	177	23.1
A103	E. - P.L.L.	10	9.6	23.6	246	16.7
11.0%	E. - M.L.	10	16.2	21.2	171	13.8

NOTE :

1. All moisture readings taken using a Marconi Moisture Meter and whole grains.

2. F. - flat position

   E. - edge position

   P.L.L. - proportional limit load

   M.L. - maximum or fracture load.

TABLE 4. - MEAN LOAD AND MEAN INDEX VALUES FOR ALL SAMPLES FOR WHICH SYMES' INDEX KNOWN.

VARIETY NAME	VARIETY NUMBER	SYMES' P.S.I.	FLAT PROP LIMIT			FLAT MAX. LOAD			EDGE PROP LIMIT			EDGE MAX LOAD		
			No. of Readings	Mean Load	Mean Index	No. of Readings	Mean Load	Mean Index	No. of Readings	Mean Load	Mean Index	No. of Readings	Mean Load	Mean Index
DURAL	187	5.8	18	33.3	690	17	40.5	570	10	22.9	644	10	43.5	560
FALCON	562	12.5	15	19.2	454	15	28.0	347	10	16.7	328	10	29.3	252
	6502		10	21.3	486	10	30.0	385	7	18.8	451	7	34.1	330
	6507		10	11.9	323	10	20.5	261	10	16.1	284	10	23.6	235
	6518		10	18.4	426	10	25.5	380	10	16.3	343	10	26.0	277
	GRAND MEANS		45	17.9	426	45	26.2	344	37	16.8	343	37	27.8	269
FESTI-GUAY	285	12.9	10	17.4	406	10	22.9	366	10	16.9	428	10	22.9	347
	563		15	15.0	376	15	21.2	310	10	15.9	436	10	27.0	316
	746		10	19.9	443	10	28.6	387	10	21.4	478	10	27.2	449
	6505		10	15.6	412	10	19.2	307	10	15.0	326	10	25.5	267
	6511		10	17.0	424	10	23.4	291	10	15.9	385	10	28.0	275
	GRAND MEANS		55	16.8	409	55	22.9	330	50	17.0	411	50	26.2	331
GALA	204	14.1	15	19.8	420	15	24.1	357	9	20.9	488	9	32.4	410
	288		9	14.0	365	9	20.8	294	10	18.7	452	10	29.2	340
	748		10	24.9	467	10	30.8	410	10	22.1	533	10	32.1	418
	GRAND MEANS		34	19.8	419	34	25.2	356	29	20.5	491	29	31.2	389

TABLE 4 (contd) - MEAN LOAD & MEAN INDEX VALUES FOR ALL SAMPLES FOR WHICH SYMES' INDEX KNOWN.

VARIETY NAME	VARIETY NUMBER	SYMES' P.S.I.	FLAT PROP LIMIT			FLAT MAX. LOAD			EDGE PROP LIMIT			EDGE MAX. LOAD		
			No. of Read-ings.	Mean Load	Mean Index	No. of Read-ings.	Mean Load	Mean Index	No. of Read-ings.	Mean Load	Mean Index	No. of Read-ings.	Mean Load	Mean Index
GABO	201	14.3	18	19.4	401	17	26.6	328	9	18.9	488	9	33.5	334
	289		10	16.2	369	10	22.6	330	10	20.3	494	10	27.5	407
	747		10	27.1	572	10	37.5	518	10	20.4	518	10	30.0	397
	GRAND MEANS		38	20.6	438	37	28.5	380	29	19.9	501	29	30.2	381
SPICA	205	18.6	15	15.6	370	15	20.3	314	10	15.5	390	10	25.9	327
	291		10	10.1	335	10	13.7	276	10	17.2	419	10	26.4	340
	498		15	13.5	357	15	18.1	312	9	15.8	420	9	26.7	337
	501		13	15.1	412	13	19.7	346	10	17.9	479	10	29.2	401
	504		15	14.9	406	15	19.1	370	10	17.8	440	10	28.9	379
	507		14	13.7	389	14	18.1	346	10	18.6	467	10	29.4	418
	753		10	15.2	446	10	18.9	397	9	18.6	462	9	30.1	360
	GRAND MEANS		92	14.1	387	92	18.5	337	68	17.3	439	68	28.1	367
WINDEBRI	6513	18.9	10	11.6	310	10	18.4	255	10	16.4	434	10	28.1	282
MENGAVI	200	22.6	15	14.1	346	15	21.6	299	10	13.6	361	10	18.0	307

TABLE 4 (contd) - MEAN LOAD & MEAN INDEX VALUES FOR ALL SAMPLES FOR WHICH SYMES' INDEX KNOWN.

VARIETY NAME	VARIETY NUMBER	SYMES' P.S.I.	FLAT PROP. LIMIT			FLAT MAX. LOAD			EDGE PROP. LIMIT			EDGE MAX. LOAD		
			No. of Readings.	Mean Load	Mean Index	No. of Readings.	Mean Load	Mean Index	No. of Readings.	Mean Load	Mean Index	No. of Readings.	Mean Load	Mean Index
GAMENYA	202	23.2	18	16.8	344	18	21.2	304	7	13.5	324	7	26.0	237
	6501		10	15.0	368	10	22.6	279	9	13.9	320	9	23.0	234
	6506		10	7.5	203	10	15.0	145	9	9.3	193	9	18.0	142
GRAND MEANS			48	13.2	306	48	19.4	248	35	11.6	268	35	20.9	195
BORDAN	6514	25.8	10	13.1	340	10	19.2	257	10	14.0	345	10	24.8	227
GLEN-WARI	564	27.3	14	12.3	313	14	18.5	250	10	15.1	438	10	22.1	340
	6515		10	11.9	313	10	18.9	234	10	14.9	371	10	23.9	261
GRAND MEANS			24	12.1	313	24	18.7	243	20	15.0	405	20	23.0	301
PINNACLE	206	28.4	10	10.7	284	10	19.9	212	10	10.4	306	10	18.8	191
	6510		10	13.7	315	10	24.1	196	10	12.8	318	10	24.3	183
GRAND MEANS			20	12.2	300	20	22.0	204	20	11.6	311	20	21.6	187

TABLE 4 (contd) - MEAN LOAD & MEAN INDEX VALUES FOR ALL SAMPLES FOR WHICH SYMES' INDEX KNOWN.

VARIETY NAME	VARIETY NUMBER	SYMES' P.S.I.	FLAT PROP. LIMIT			FLAT MAX. LOAD			EDGE PROP. LIMIT			EDGE MAX. LOAD		
			No. of Readings.	Mean Load	Mean Index	No. of Readings.	Mean Load	Mean Index	No. of Readings.	Mean Load	Mean Index	No. of Readings.	Mean Load	Mean Index.
HERON	565	29.5	16	14.6	337	16	24.0	255	9	16.5	459	9	29.1	300
	6503		10	9.6	326	10	21.7	188	10	9.3	249	10	20.1	158
	6508		10	8.6	257	10	17.4	154	10	10.1	198	10	17.0	147
	6512		10	11.4	323	10	21.6	200	10	12.5	336	10	24.5	202
	6519		10	9.4	289	10	17.2	188	10	9.6	249	10	21.6	146
GRAND MEANS			56	11.1	310	56	20.8	203	49	11.5	295	49	22.3	188
CHILE 1B	561	31.9	14	13.7	351	14	22.7	242	9	11.3	284	9	23.5	191
MEXICO 120	566	32.3	14	11.1	273	14	17.7	221	8	11.2	268	8	25.1	218
TOTAL NO. OF READINGS			537			535			433			433		

TOTAL NUMBER OF VARIETIES - 16 - LOADING RATE - 0.26 in./min.

MOISTURE CONTENT RANGE - 11 to 13% , MEASURED WITH A MARCONI MOISTURE METER.

NOTE : Symes' Particle Size Index is not known for Mendos or Olympic A103 so these samples have been excluded from this Table and the regression equations of Load and Load Index v's Symes' Index.

TABLE 5 LOAD INDEX V'S SYMES' PARTICLE SIZE INDEX - REGRESSION EQUATIONS

SAMPLE GROUPING	LOADING POSITION	NUMBER OF VARIETIES	NUMBER OF READINGS	LINEAR REGRESSION EQUATIONS	F. RATIO	CORRELATION COEFFICIENT	STUDENT'S T
1964/65 & 1965/66 HARVEST SAMPLES	F. - P.L.L.	15	493	L.I. = 564 - 9.35 x S.I.	9.53	-0.559	14.96
	F. - M.L.	15	491	L.I. = 499 - 9.78 x S.I.	7.69	-0.625	17.70
	E. - P.L.L.	15	394	L.I. = 563 - 8.85 x S.I.	11.74	-0.477	10.74
	E. - M.L.	15	394	L.I. = 487 - 9.57 x S.I.	16.21	-0.580	14.10
1964/65 & 1965/66 HARVEST SAMPLES LESS 187 DURAL	F. - P.L.L.	14	475	L.I. = 510 - 7.06 x S.I.	2.69	-0.465	11.41
	F. - M.L.	14	474	L.I. = 464 - 8.24 x S.I.	4.08	-0.563	14.80
	E. - P.L.L.	14	384	L.I. = 537 - 7.71 x S.I.	11.07	-0.419	9.02
	E. - M.L.	14	384	L.I. = 461 - 8.46 x S.I.	15.04	-0.527	12.12
1964/65 & 1965/66 HARVEST SAMPLES OF VARIETIES FOR WHICH SYMES' P.S.I. HAS BEEN DETERMINED 5 x OR MORE	F. - P.L.L.	9	348	L.I. = 534 - 8.12 x S.I.	1.97	-0.469	9.88
	F. - M.L.	9	347	L.I. = 504 -10.02 x S.I.	3.28	-0.584	13.36
	E. - P.L.L.	9	278	L.I. = 523 - 7.18 x S.I.	17.00	-0.362	6.45
	E. - M.L.	9	278	L.I. = 464 - 8.67 x S.I.	24.88	-0.494	9.43

TABLE 5 (Cont'd.) - LOAD INDEX V'S SYMES' PARTICLE SIZE INDEX - REGRESSION EQUATIONS

SAMPLE GROUPING	Loading Position	Number of Varieties	Number of Readings	LINEAR REGRESSION EQUATIONS	F. Ratio	Correlation Coefficient	Student's T
1964/65 Harvest Samples	F - P.L.L.	13	333	LI = 585 - 9.94 x SI	8.45	-0.562	12.37
	F - M.L.	13	331	LI = 511 - 9.41 x SI	4.93	-0.594	13.39
	E - P.L.L.	13	239	LI = 597 - 8.80 x SI	6.59	-0.461	8.00
	E - M.L.	13	239	LI = 514 - 9.10 x SI	7.55	-0.547	10.07
1964/65 Harvest Samples Less 187 Dural	F - P.L.L.	12	315	LI = 513 - 6.70 x SI	1.56	-0.427	8.36
	F - M.L.	12	314	LI = 463 - 7.26 x SI	1.24	-0.498	10.16
	E - P.L.L.	12	229	LI = 565 - 7.30 x SI	6.14	-0.381	6.20
	E - M.L.	12	229	LI = 481 - 7.57 x SI	6.54	-0.466	7.94
1964/65 Harvest Samples Number 200 to 206	F - P.L.L.	6	91	LI = 528 - 8.23 x SI	0.24	-0.510	5.59
	F - M.L.	6	90	LI = 450 - 7.21 x SI	1.68	-0.472	5.02
	E - P.L.L.	6	55	LI = 663 - 13.32 x SI	0.33	-0.500	4.20
	E - M.L.	6	55	LI = 556 - 12.53 x SI	1.78	-0.635	5.99

SAMPLE GROUPING	Loading Position	Number of Varieties	Number of Readings	LINEAR REGRESSION EQUATIONS	F. Ratio	Correlation Coefficient	Student's T
1964/65 Harvest Samples of Varieties for which Symes' P.S.I. has been determined 5 times or more.	F- P.L.L.	8	218	LI = 551 - 8.56 x SI	0.79	-0.424	6.87
	F- M.L.	8	217	LI = 491 - 8.48 x SI	1.11	-0.450	7.38
	E- P.L.L.	8	153	LI = 511 - 4.33 x SI	8.77	-0.197	2.48
	E- M.L.	8	153	LI = 448 - 5.76 x SI	10.17	-0.305	3.94
1965/66 Harvest Samples	F-P.L.L.	8	160	LI = 485 - 6.74 x SI	2.87	-0.481	6.89
	F-M.L.	8	160	LI = 423 - 8.03 x SI	2.51	-0.641	10.49
	E- P.L.L.	8	155	LI = 419 - 4.75 x SI	8.64	-0.347	4.58
	E- M.L.	8	155	LI = 352 - 5.96 x SI	6.31	-0.572	8.61
1965/66 Harvest samples of varieties for which Symes' P.S.I. has been determined 5 times or more	F- P.L.L.	6	130	LI = 477 - 6.38 x SI	3.10	-0.440	5.54
	F- M.L.	6	130	LI = 448 - 8.94 x SI	2.64	-0.654	9.78
	E- P.L.L.	6	125	LI = 389 - 3.82 x SI	7.50	-0.271	3.12
	E- M.L.	6	125	LI = 343 - 5.70 x SI	6.99	-0.512	6.62

TABLE 6 - LOAD V'S SYMES' PARTICLE SIZE INDEX - REGRESSION EQUATIONS

SAMPLE GROUPING	Loading Position	Number of Varieties	Number of Readings	LINEAR REGRESSION EQUATIONS	F. Ratio	Correlation Coefficient	Student's T
1964/65 & 1965/66 Harvest Samples	F - P.L.L.	15	493	L = 25.9 - 0.52 x SI	11.44	-0.550	14.60
	F - M.L.	15	491	L = 30.7 - 0.42 x SI	13.74	-0.390	9.36
	E - P.L.L.	15	394	L = 23.9 - 0.41 x SI	6.11	-0.589	14.43
	E - M.L.	15	394	L = 35.5 - 0.47 x SI	8.84	-0.471	10.57
1964/65 & 1965/66 Harvest Samples Less 187 Dural	F - P.L.L.	14	475	L = 22.8 - 0.39 x SI	4.46	-0.460	11.27
	F - M.L.	14	475	L = 27.3 - 0.27 x SI	8.21	-0.271	6.11
	E - P.L.L.	14	384	L = 23.6 - 0.40 x SI	6.67	-0.565	13.38
	E - M.L.	14	384	L = 33.4 - 0.38 x SI	6.14	-0.400	8.54
1964/65 & 1965/66 Harvest Samples of varieties for which Symes' P.S.I. has been determined 5 x or more.	F - P.L.L.	9	348	L = 23.7 - 0.44 x SI	3.78	-0.463	9.72
	F - M.L.	9	347	L = 28.3 - 0.32 x SI	11.58	-0.278	5.37
	E - P.L.L.	9	278	L = 23.9 - 0.41 x SI	8.13	-0.545	10.80
	E - M.L.	9	278	L = 35.0 - 0.46 x SI	5.97	-0.433	7.98

TABLE 6 (Cont'd.) - LOAD V'S SYMES' PARTICLE SIZE INDEX - REGRESSION EQUATIONS

SAMPLE GROUPING	Loading Position	Number of Varieties	Number of Readings	LINEAR REGRESSION EQUATIONS	F. Ratio	Correlation Coefficient	Student's T
1964/65 HARVEST SAMPLES	F - P.L.L.	13	333	L = 27.1-0.54 x SI	11.53	-0.535	11.51
	F - M.L.	13	331	L = 32.4-0.49 x SI	13.69	-0.412	8.20
	E - P.L.L.	13	239	L = 24.7-0.40 x SI	3.87	-0.578	10.89
	E - M.L.	13	239	L = 36.7-0.48 x SI	9.33	-0.445	7.65
1964/65 Harvest Samples Less 187 Dural	F - P.L.L.	12	315	L = 22.9-0.36 x SI	5.06	-0.402	7.76
	F - M.L.	12	314	L = 27.8-0.29 x SI	8.71	-0.256	4.68
	E - P.L.L.	12	229	L = 24.5 -0.40 x SI	4.47	-0.551	9.95
	E - M.L.	12	229	L = 33.5-0.34 x SI	6.86	-0.332	5.29
1964/65 Harvest Samples number 200 → 206	F - P.L.L.	6	91	L = 27.1-0.54 x SI	1.73	-0.500	5.45
	F - M.L.	6	90	L = 30.2-0.39 x SI	1.27	-0.300	2.95
	E - P.L.L.	6	55	L = 27.4-0.59 x SI	0.16	-0.699	7.13
	E - M.L.	6	55	L = 43.6-0.91 x SI	1.98	-0.588	5.29

TABLE 6 (Cont'd.) LOAD V'S SYMES' PARTICLE SIZE INDEX - REGRESSION EQUATIONS

Sample Grouping	Loading Position	Number of Groups	Number of Readings	Linear Regression Equations	F. Ratio	Correlation Coefficient	Student's T
1964/65 Harvest samples of varieties for which Symes' P.S.I. has been determined 5 times or more.	F - P.L.L.	8	218	L = 23.6-0.40xSI	6.53	-0.361	5.70
	F - M.L.	8	217	L = 28.7-0.35 xSI	12.15	-0.235	3.55
	E - P.L.L.	8	153	L = 24.0.37 x SI	5.95	-0.455	6.28
	E - M.L.	8	153	L = 36.8 -0.51 x SI	6.80	-0.388	5.17
1965/66 Harvest Samples	F - P.L.L.	8	160	L = 21.0-0.37 x SI	2.78	-0.517	7.60
	F - M.L.	8	160	L = 25.7-0.23 x SI	4.10	-0.269	3.51
	E - P.L.L.	8	155	L = 20.2-0.31 x SI	4.65	-0.506	7.26
	E - M.L.	8	155	L = 31.2 - 0.34 x SI	4.48	-0.407	5.52
1965/66 Harvest samples of varieties for which Symes' P.S.I. has been determined 5 times or more	F - P.L.L.	6	130	L = 21.7-0.39 x SI	3.10	-0.514	6.77
	F - M.L.	6	130	L = 28.2-0.31 x SI	4.67	-0.351	4.24
	E - P.L.L.	6	125	L = 20.5-0.32 x SI	5.51	-0.487	6.19
	E - M.L.	6	125	L = 30.2-0.31 x SI	5.55	-0.355	4.21

TABLE 7 - PEARLING INDEX FOR 1965/66 SAMPLES

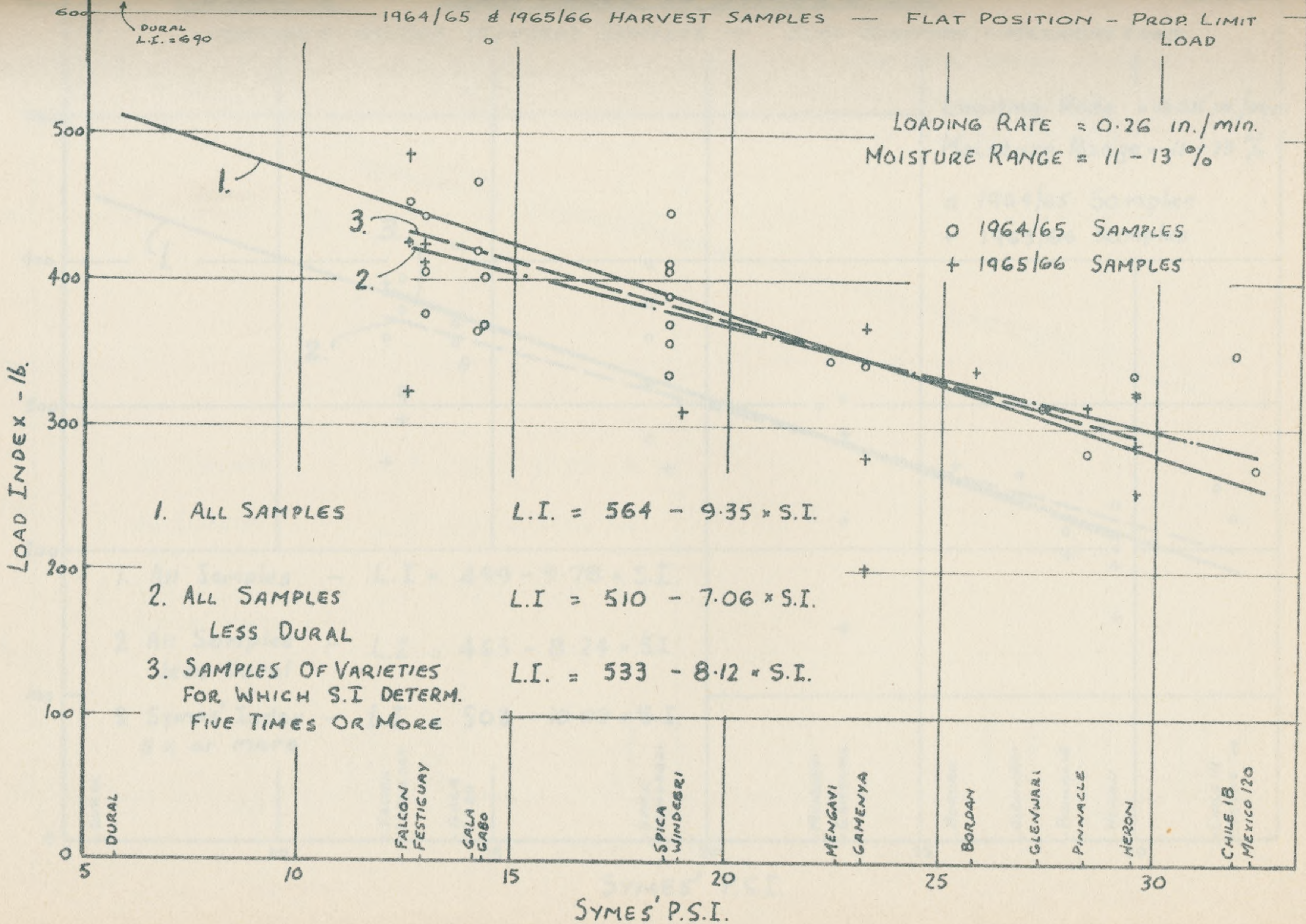
Sample Number	Variety	Pearling Index
6501	Gamenya	4.93
6502	Falcon	5.33
6503	Heron	3.35
6504	Mendos	5.25
6505	Festiguay	5.55
6506	Gamenya	2.98
6507	Falcon	4.53
6508	Heron	3.10
6509	Olympic A103	2.50
6510	Pinnacle	3.15
6511	Festiguay	4.70
6512	Heron	3.90
6513	Windebri	4.70
6514	Bordan	3.73
6515	Glenwari	3.08
6516	Olympic A103	2.98
6517	Gamenya	3.85
6518	Falcon	5.25
6519	Heron	3.30
6520	Olympic A103	3.13

TABLE 8 LOAD INDEX V'S PEARLING INDEX - REGRESSION EQUATIONS

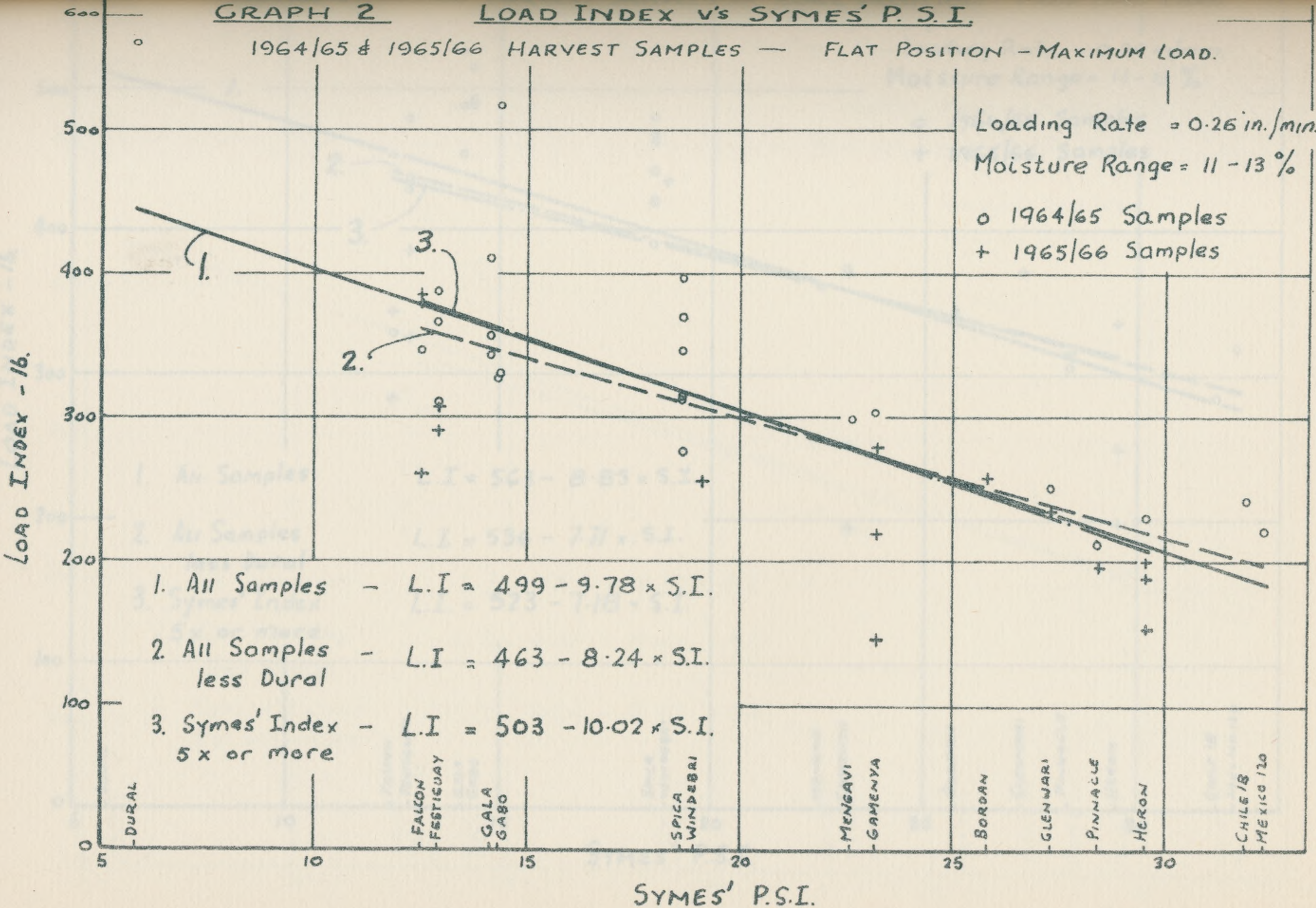
SAMPLE GROUPING	Loading Position	Number of Groups	Number of Readings	LINEAR REGRESSION EQUATIONS	F. Ratio	Correlation Coefficient	Student's T
1965/66 Harvest Samples	F - P.L.L.	17	200	LI=49.2 + 69.6 x P.I.	2.79	0.659	12.33
	F - M.L.	17	200	LI=-43.9 + 70.7 x P.I.	3.11	0.748	15.88
	E - P.L.L.	17	195	LI=101.7 + 51.9 x P.I.	7.50	0.510	8.24
	E - M.L.	17	195	LI = 17.6 + 50.2 x P.I.	4.93	0.650	11.87

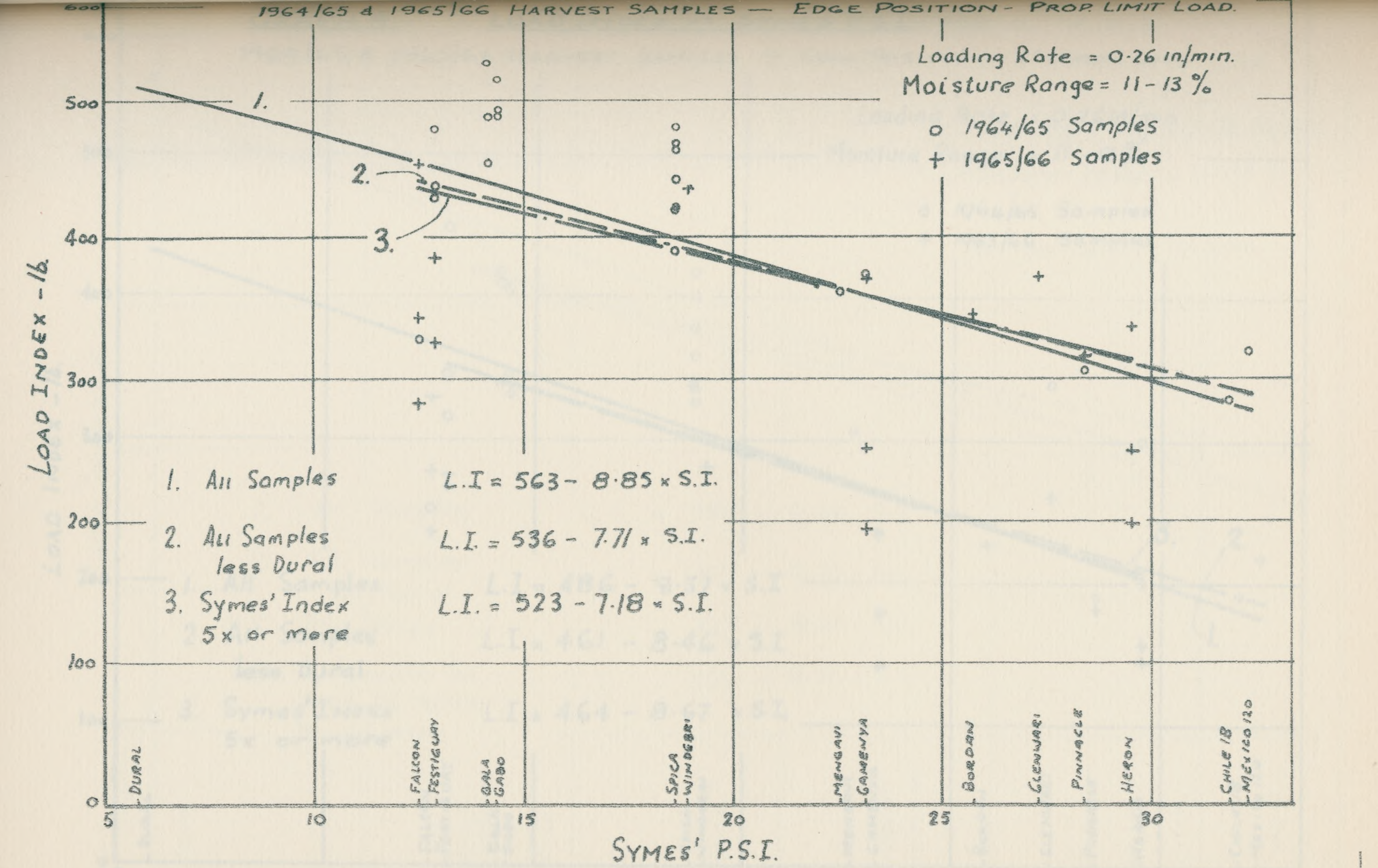
TABLE 9 LOAD V'S PEARLING INDEX - REGRESSION EQUATIONS

1965/66 Harvest Samples	F - P.L.L.	17	200	L = - 2.21+3.68 x PI	4.09	0.679	13.00
	F - M.L.	17	200	L = 6.37+3.41 x PI	5.85	0.511	8.37
	E - P.L.L.	17	195	L = 2.34 + 2.69x PI	3.71	0.587	10.07
	E - M.L.	17	195	L = 8.78+3.49 x PI	6.97	0.544	9.01



1964/65 & 1965/66 HARVEST SAMPLES — FLAT POSITION - PROP. LIMIT LOAD
DURAL L.I. = 690
LOADING RATE = 0·26 in./min.
MOISTURE RANGE = 11 - 13 %
o 1964/65 SAMPLES
+ 1965/66 SAMPLES
1.
2.
3.
1. ALL SAMPLES L.I. = 564 - 9·35 × S.I.
2. ALL SAMPLES LESS DURAL L.I = 510 - 7·06 × S.I.
3. SAMPLES OF VARIETIES FOR WHICH S.I DETERM. FIVE TIMES OR MORE L.I. = 533 - 8·12 × S.I.
LOAD INDEX - lb.
600
500
400
300
200
100
0
5
10
15
20
25
30
DURAL
FALCON
FESTIGUAY
GALA
GABO
SPICA
WINDEBRI
MENGAVI
GAMENYA
BORDAN
GLENWARI
PINNACLE
HERON
CHILE 1B
MEXICO 120
SYMES' P.S.I.

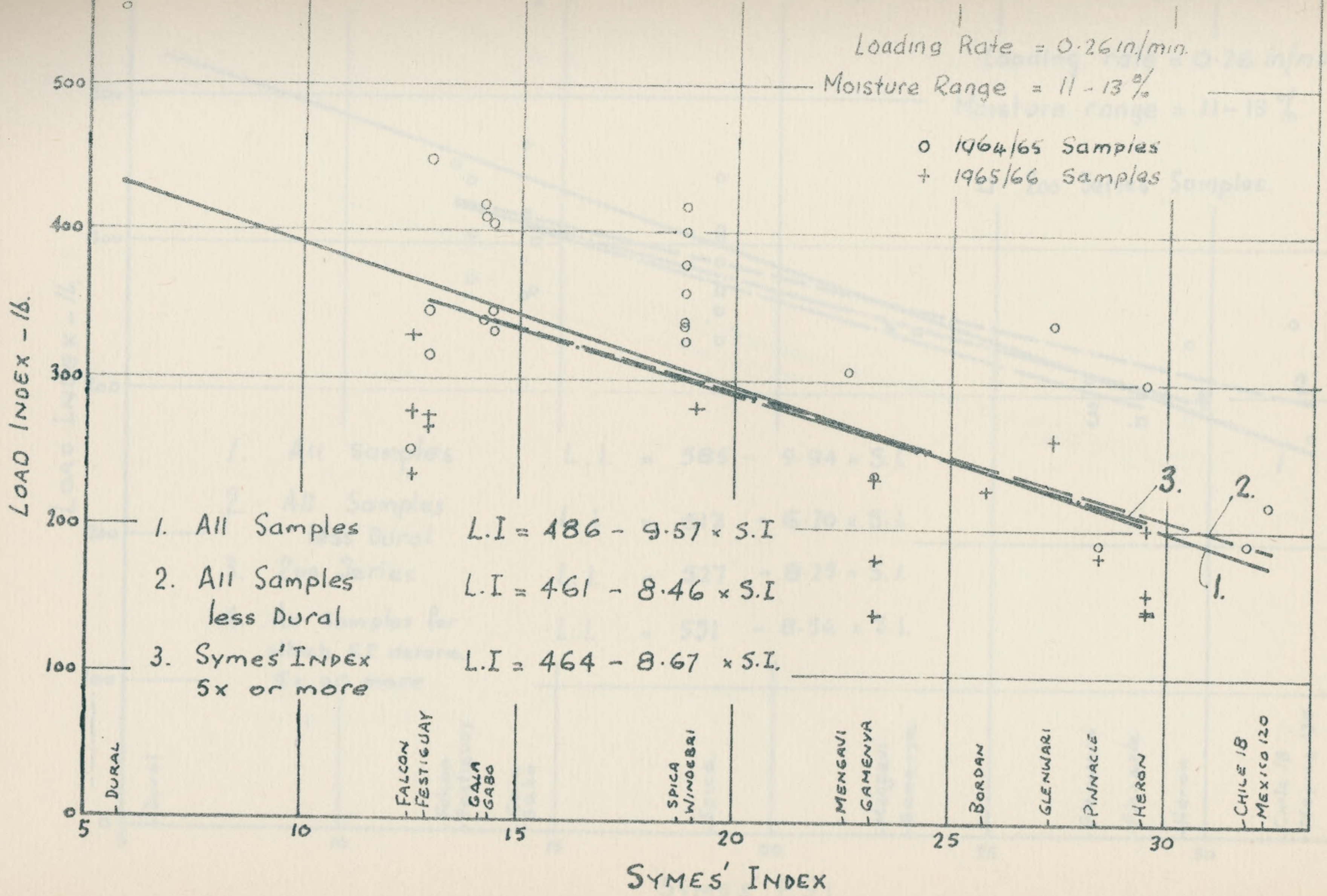

GRAPH 2 LOAD INDEX V'S SYMES' P.S.I.
1964/65 & 1965/66 HARVEST SAMPLES — FLAT POSITION - MAXIMUM LOAD.
Loading Rate = 0·26 in./min.
Moisture Range = 11 - 13 %
o 1964/65 Samples
+ 1965/66 Samples
1. All Samples - L.I = 499 - 9·78 × S.I.
2. All Samples less Dural - L.I = 463 - 8·24 × S.I.
3. Symes' Index 5 x or more - L.I = 503 - 10·02 × S.I.
LOAD INDEX - lb.
SYMES' P.S.I.
DURAL
FALCON
FESTIGUAY
GALA
GABO
SPICA
WINDEBRI
MENGAVI
GAMENYA
BORDAN
GLENWARI
PINNACLE
HERON
CHILE 1B
MEXICO 120

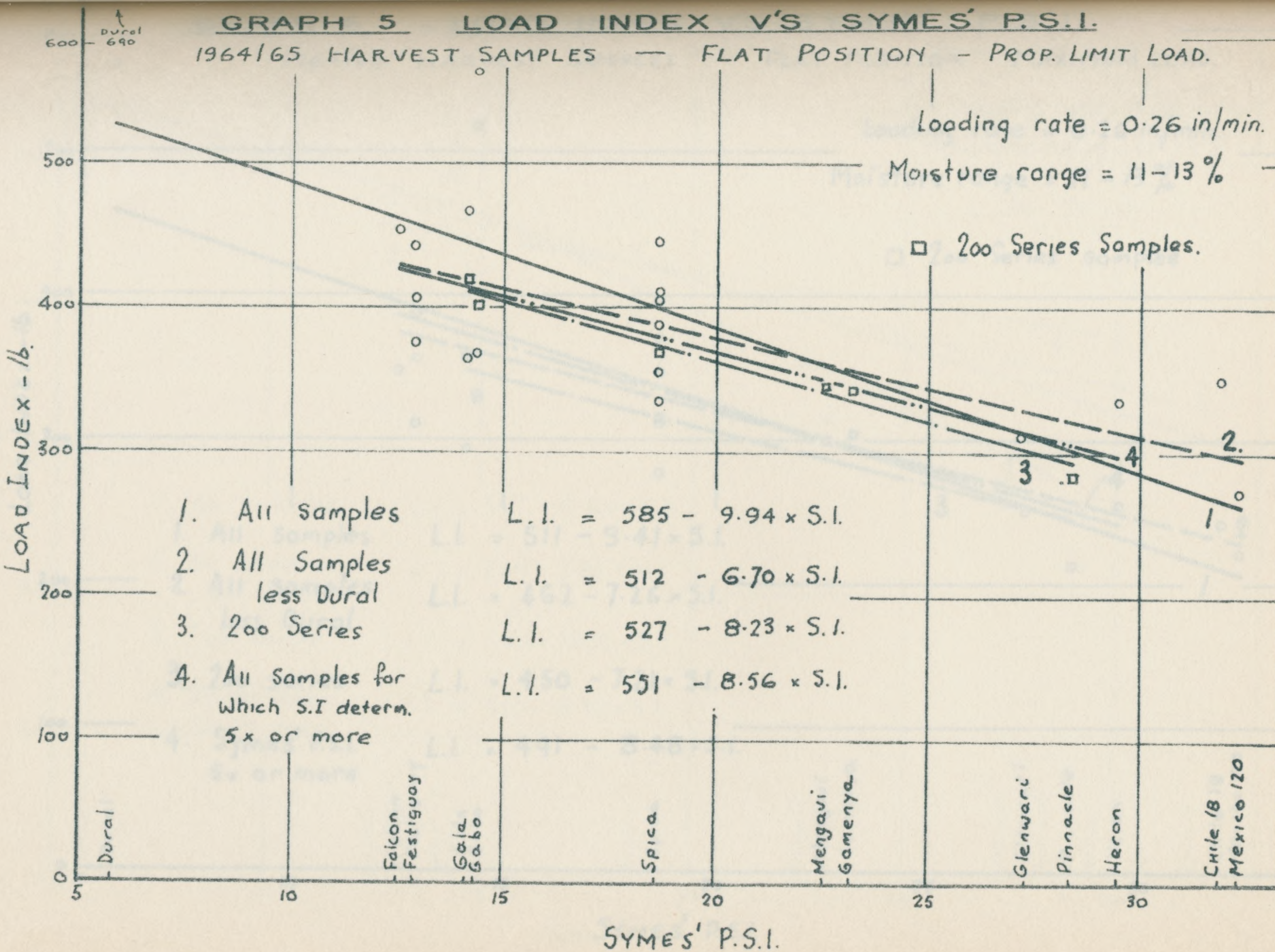


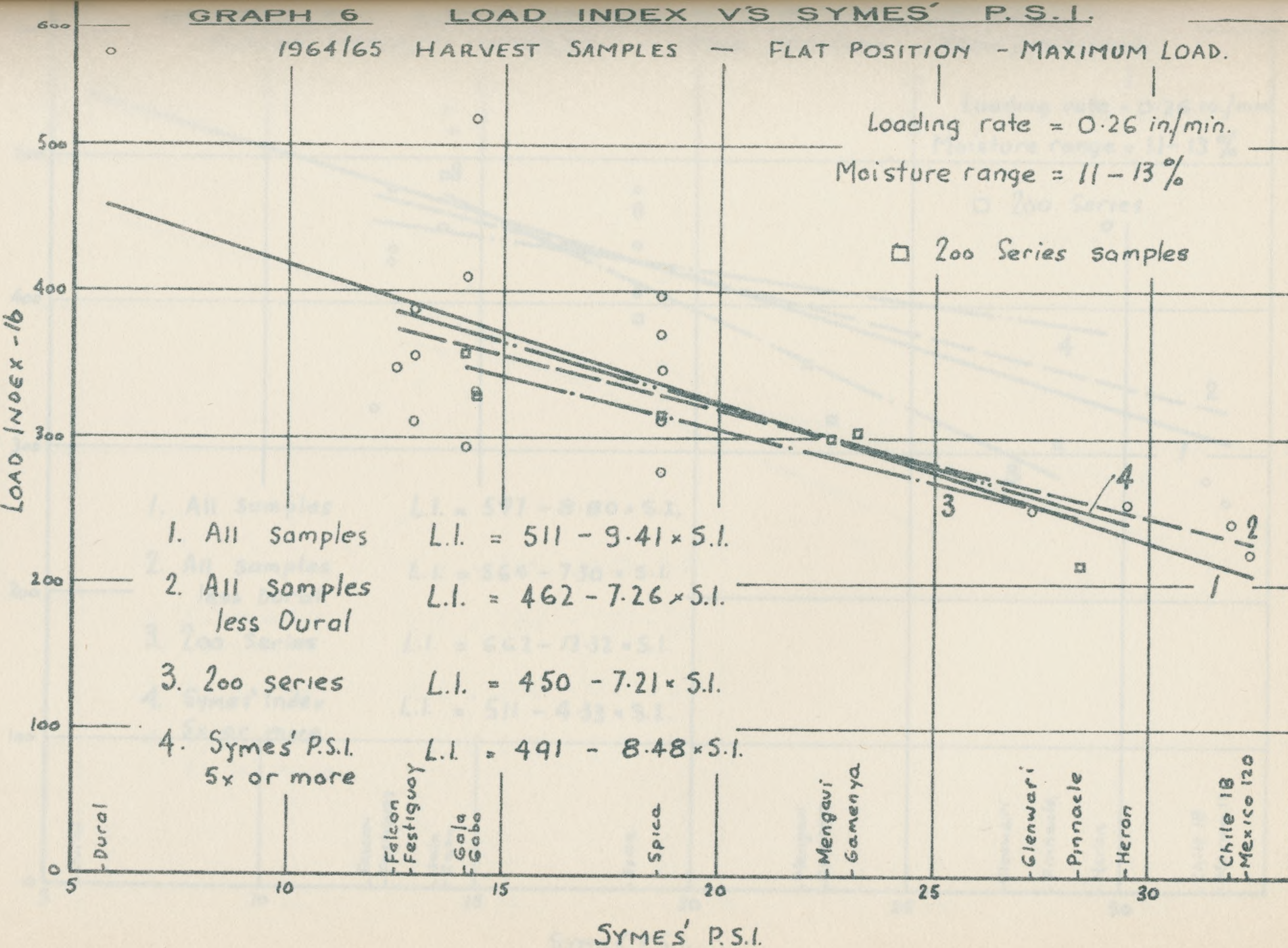
1964/65 & 1965/66 HARVEST SAMPLES — EDGE POSITION - PROP. LIMIT LOAD.
Loading Rate = 0·26 in/min.
Moisture Range = 11 - 13 %
o 1964/65 Samples
+ 1965/66 Samples
1. All Samples L.I = 563 - 8·85 × S.I.
2. All Samples less Dural L.I. = 536 - 7·71 × S.I.
3. Symes' Index 5× or more L.I. = 523 - 7·18 × S.I.
LOAD INDEX - lb.
SYMES' P.S.I.
0
100
200
300
400
500
600
5
10
15
20
25
30
DURAL
FALCON
FESTIGUAY
BALA
GABO
SPICA
WINDEBRI
MENGAVI
GAMENYA
BORDAN
GLENWARI
PINNACLE
HERON
CHILE 18
MEXICO 120

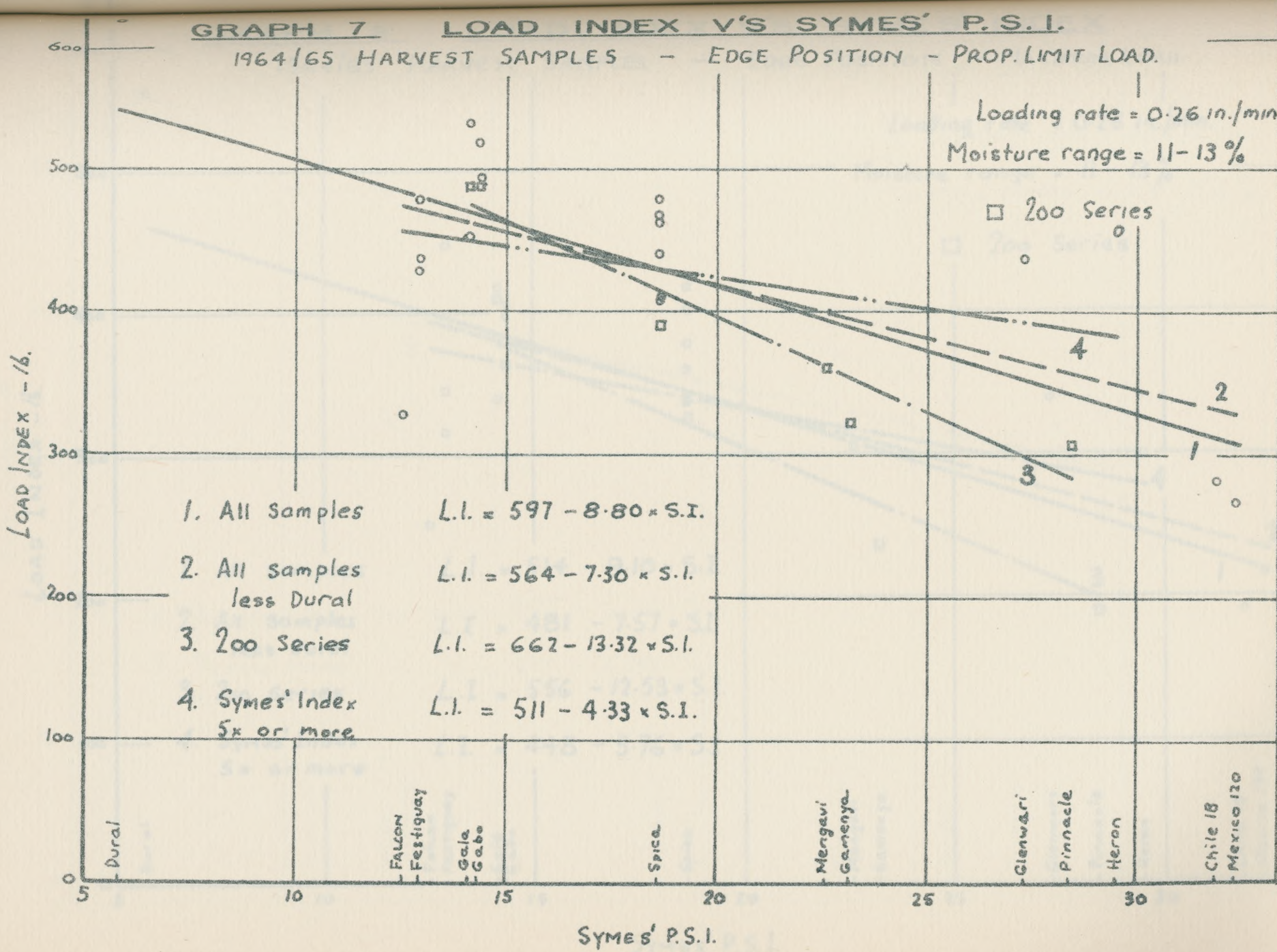
GRAPH 4 LOAD INDEX vs SYMES P.S.I.

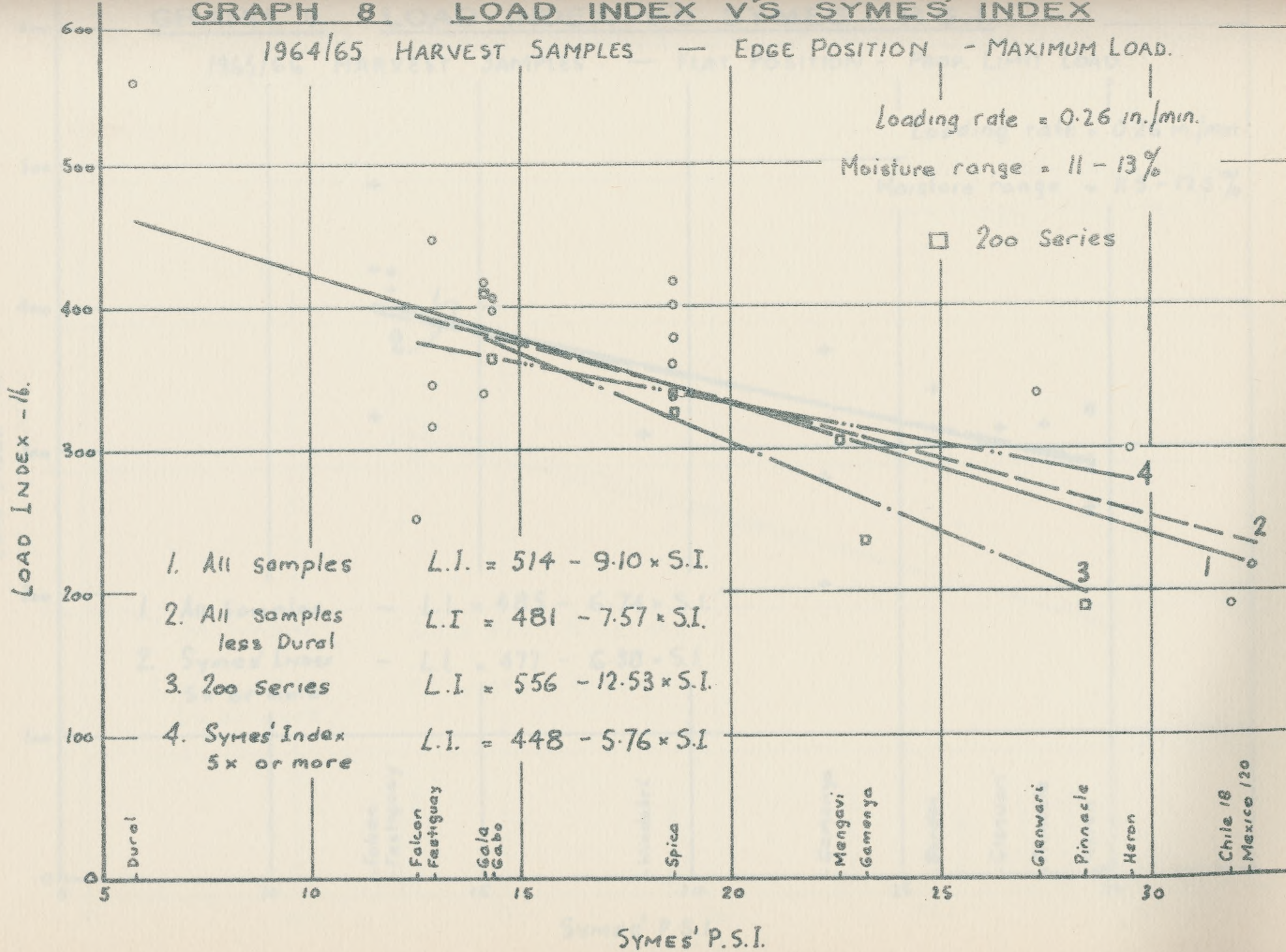
1964/65 & 1965/66 HARVEST SAMPLES — EDGE POSITION - MAXIMUM LOAD

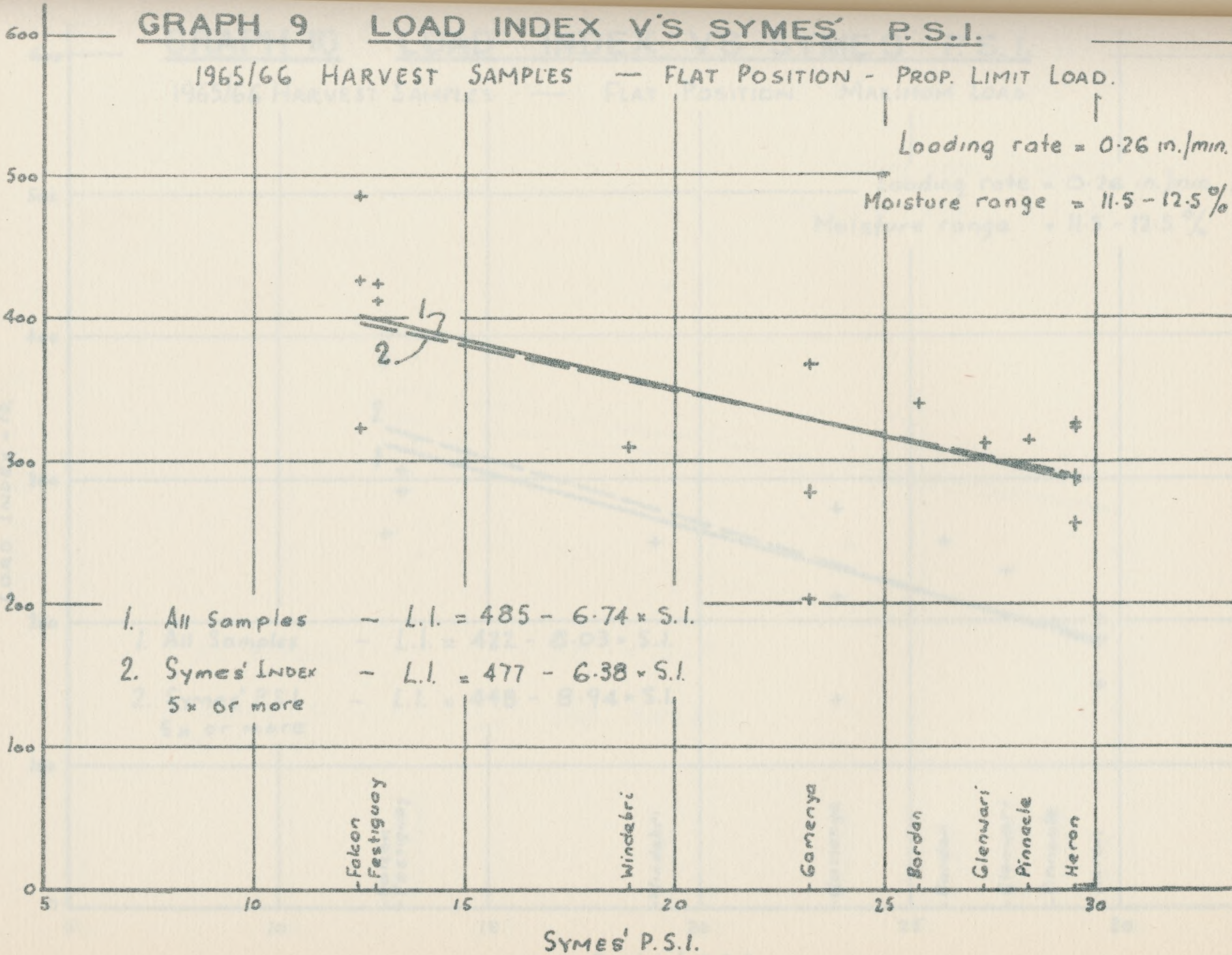


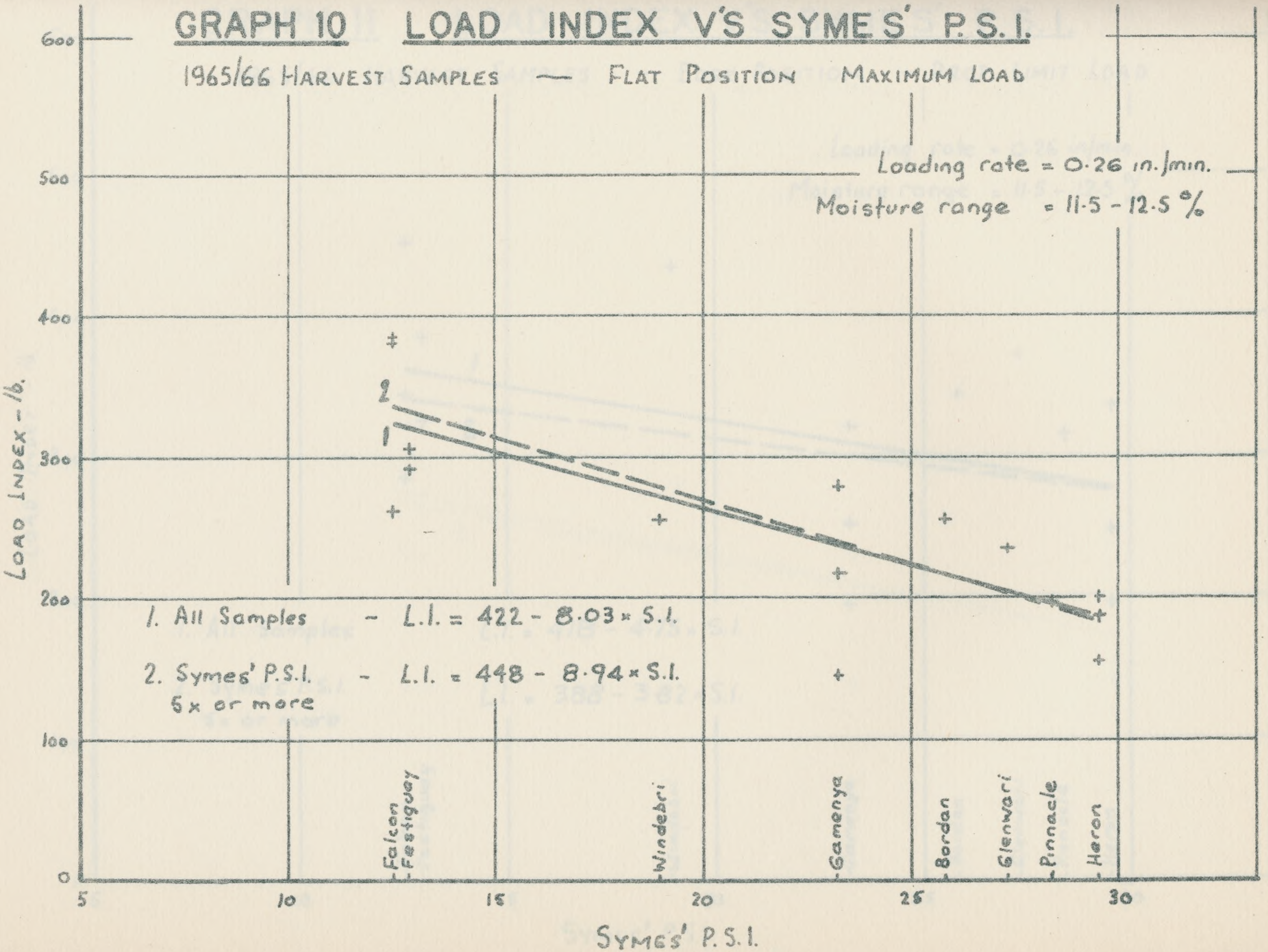

GRAPH 5 LOAD INDEX V'S SYMES' P.S.I.
1964/65 HARVEST SAMPLES — FLAT POSITION - PROP. LIMIT LOAD.
Dural 690
Loading rate = 0·26 in/min.
Moisture range = 11-13 %
200 Series Samples.
LOAD INDEX - lb.
1. All samples L.I. = 585 - 9.94 x S.I.
2. All Samples less Dural L.I. = 512 - 6.70 x S.I.
3. 200 Series L.I. = 527 - 8.23 x S.I.
4. All Samples for which S.I determ. 5x or more L.I. = 551 - 8.56 x S.I.
Dural
Falcon
Festiguay
Gala
Gabo
Spica
Mengavi
Gamenya
Glenwari
Pinnacle
Heron
Chile 18
Mexico 120
SYMES' P.S.I.

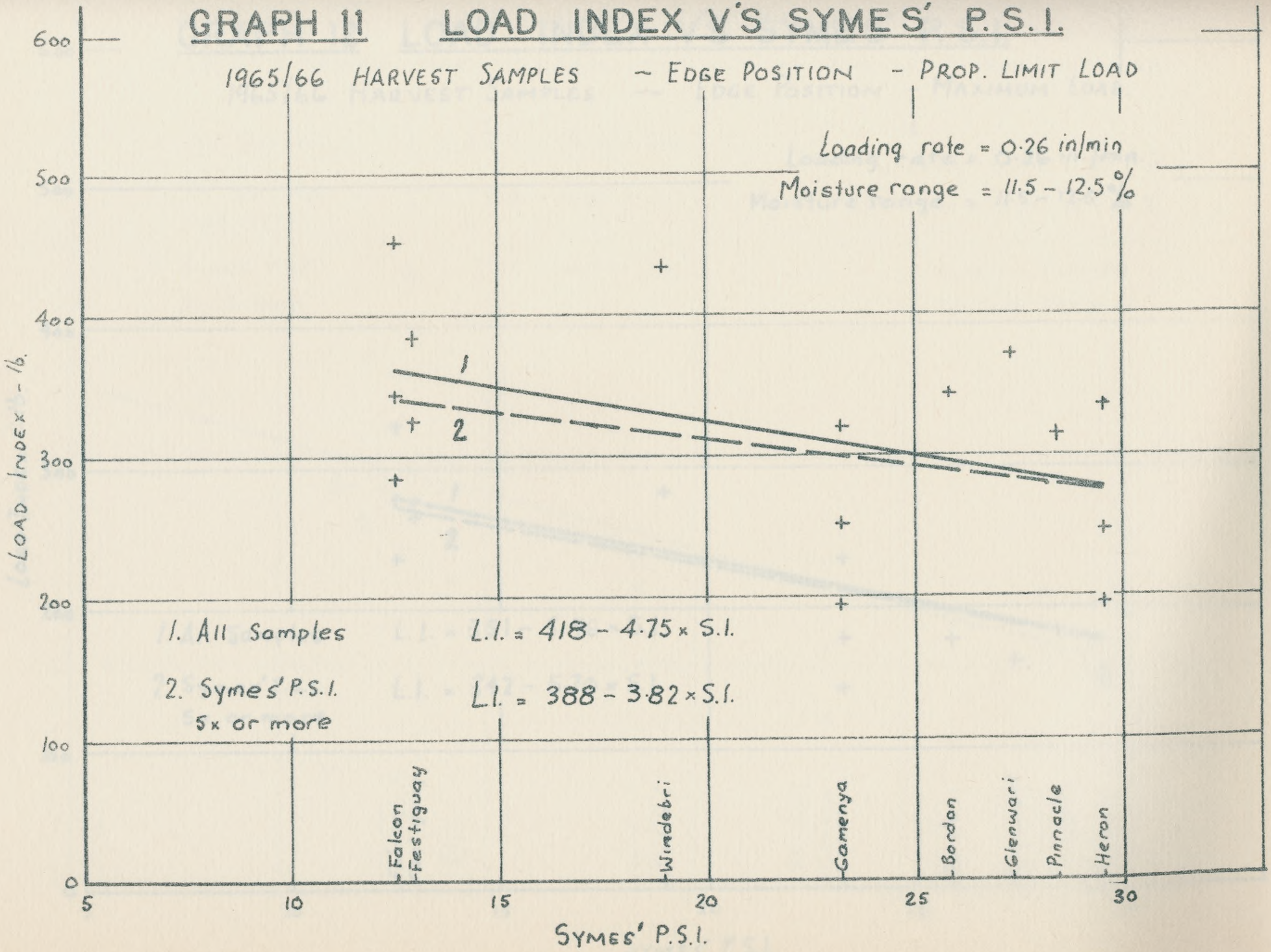

GRAPH 6 LOAD INDEX V'S SYMES' P.S.I.
1964/65 HARVEST SAMPLES — FLAT POSITION - MAXIMUM LOAD.
Loading rate = 0·26 in/min.
Moisture range = 11 - 13 %
□ 200 Series samples
1. All samples L.I. = 511 - 9·41 × S.I.
2. All samples less Dural L.I. = 462 - 7·26 × S.I.
3. 200 series L.I. = 450 - 7·21 × S.I.
4. Symes' P.S.I. 5x or more L.I. = 491 - 8·48 × S.I.
LOAD INDEX - lb
600
500
400
300
200
100
0
5
10
15
20
25
30
SYMES' P.S.I.
1
2
3
4
Dural
Falcon
Festiguay
Gala
Gabo
Spica
Mengavi
Gamenya
Glenwari
Pinnacle
Heron
Chile 1B
Mexico 120

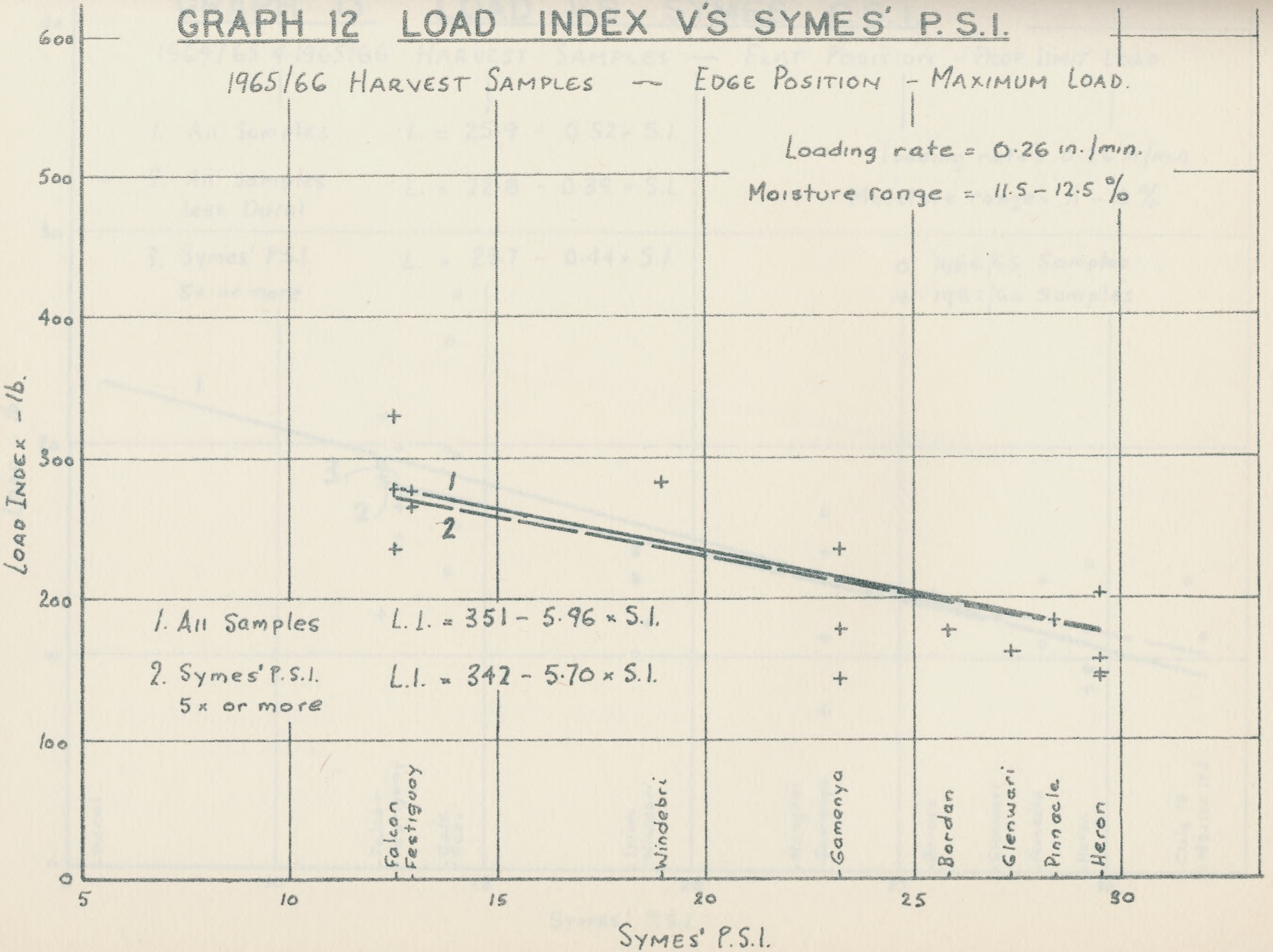

GRAPH 7 LOAD INDEX V'S SYMES' P.S.I.
1964/65 HARVEST SAMPLES - EDGE POSITION - PROP. LIMIT LOAD.
Loading rate = 0·26 in./min.
Moisture range = 11-13 %
200 Series
1
2
3
4
1. All samples L.I. = 597 - 8·80 × S.I.
2. All samples less Dural L.I. = 564 - 7·30 × S.I.
3. 200 Series L.I. = 662 - 13·32 × S.I.
4. Symes' Index 5× or more L.I. = 511 - 4·33 × S.I.
LOAD INDEX - lb.
600
500
400
300
200
100
0
5
10
15
20
25
30
SYMES' P.S.I.
Dural
FALCON
Festiguay
Gala
Gabo
Spica
Mengavi
Gamenya
Glenwari
Pinnacle
Heron
Chile 18
Mexico 120

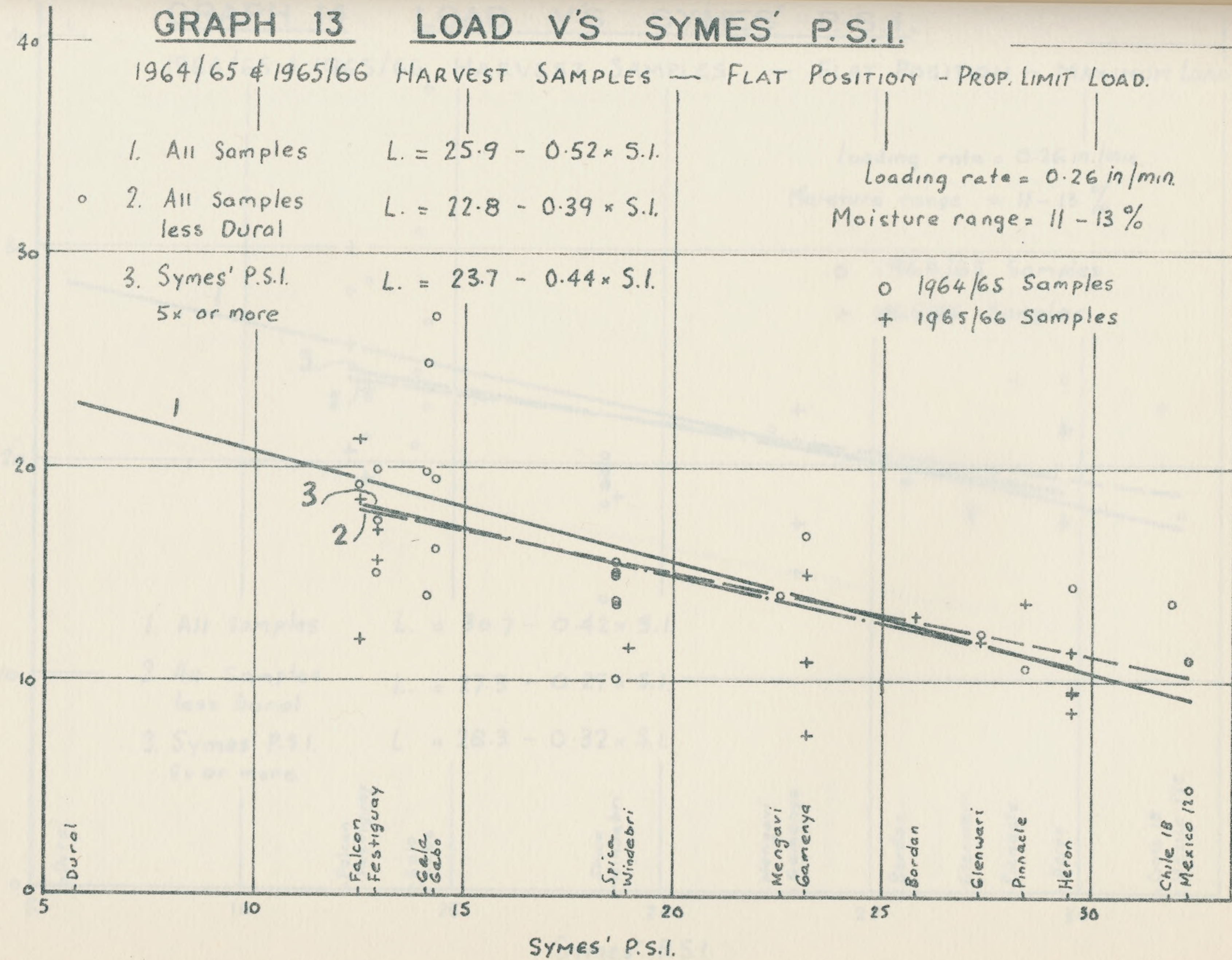

GRAPH 8 LOAD INDEX V'S SYMES' INDEX
1964/65 HARVEST SAMPLES — EDGE POSITION - MAXIMUM LOAD.
Loading rate = 0.26 in./min.
Moisture range = 11 - 13%
200 Series
1. All samples L.I. = 514 - 9.10 × S.I.
2. All samples less Dural L.I = 481 - 7.57 × S.I.
3. 200 series L.I. = 556 - 12.53 × S.I.
4. Symes' Index 5× or more L.I. = 448 - 5.76 × S.I
LOAD INDEX - lb.
SYMES' P.S.I.
Dural
Falcon
Festiguay
Gala
Gabo
Spica
Mengavi
Gamenya
Glenwari
Pinnacle
Heron
Chile 18
Mexico 120
600
500
400
300
200
100
0
5
10
15
20
25
30
1
2
3
4

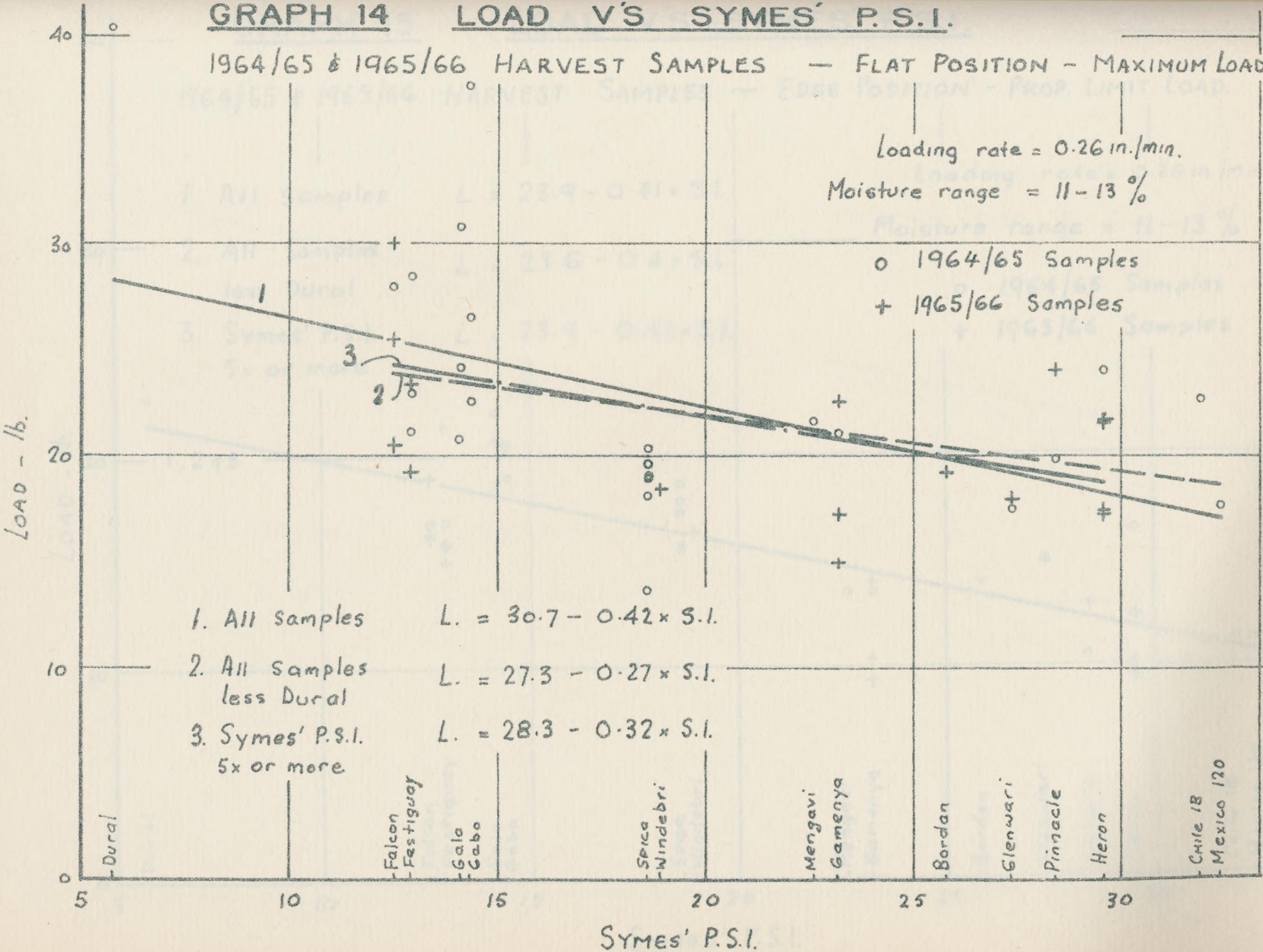

GRAPH 9 LOAD INDEX V'S SYMES' P.S.I.
1965/66 HARVEST SAMPLES — FLAT POSITION - PROP. LIMIT LOAD.
Loading rate = 0·26 in./min.
Moisture range = 11·5 - 12·5 %
1. All Samples — L.I. = 485 - 6·74 × S.I.
2. Symes' Index 5 × or more — L.I. = 477 - 6·38 × S.I.
LOAD INDEX - lb.
Symes' P.S.I.
0
100
200
300
400
500
600
5
10
15
20
25
30
Falcon
Festiguay
Windebri
Gamenya
Bordan
Glenwari
Pinnacle
Heron
1
2

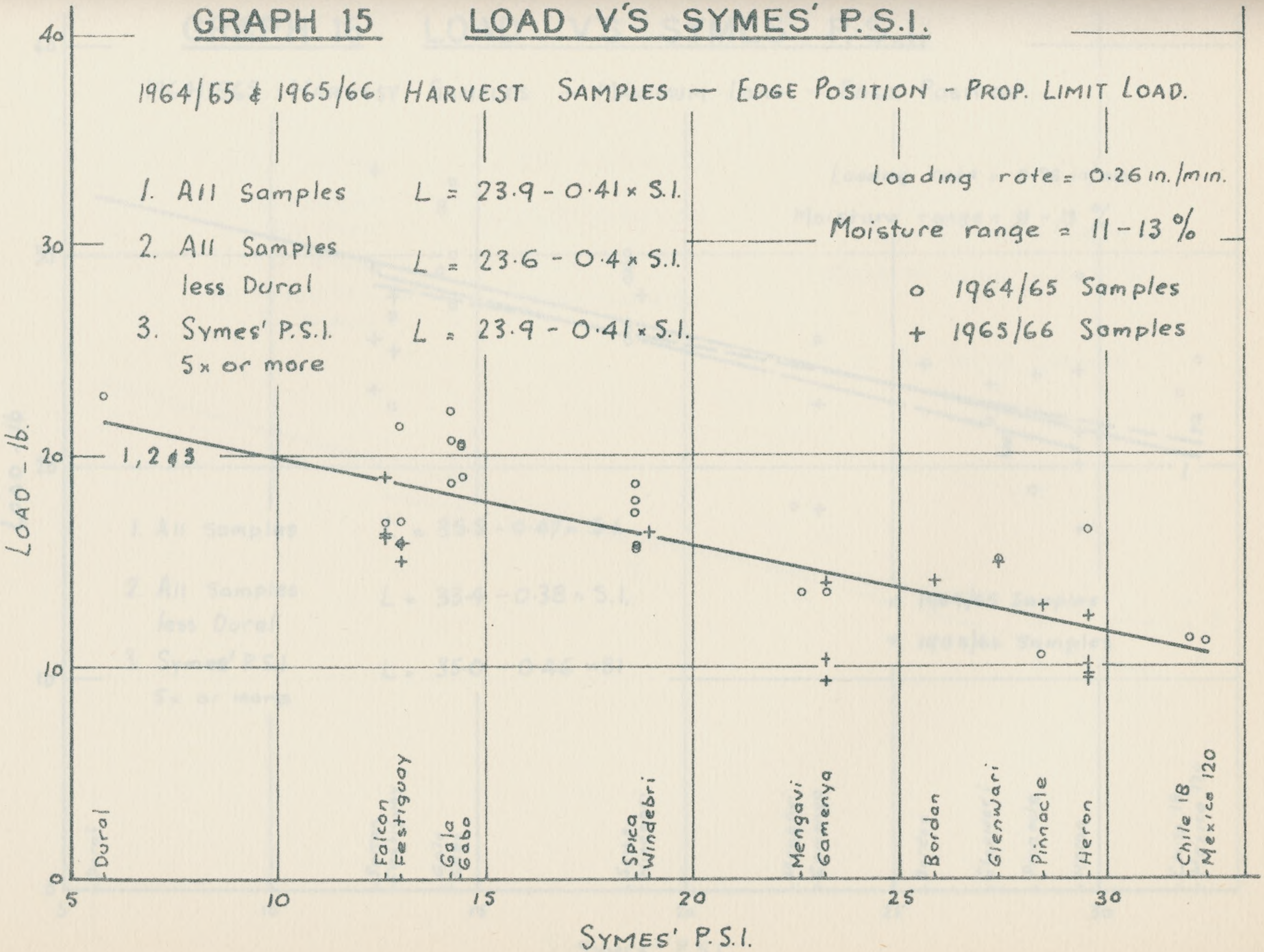

GRAPH 10 LOAD INDEX V'S SYMES' P.S.I.
1965/66 HARVEST SAMPLES — FLAT POSITION MAXIMUM LOAD
Loading rate = 0·26 in./min.
Moisture range = 11·5 - 12·5 %
1. All Samples - L.I. = 422 - 8·03 × S.I.
2. Symes' P.S.I. 5× or more - L.I. = 448 - 8·94 × S.I.
LOAD INDEX - lb.
SYMES' P.S.I.
Falcon
Festiguay
Windebri
Gamenya
Bordan
Glenwari
Pinnacle
Heron
0
100
200
300
400
500
600
5
10
15
20
25
30

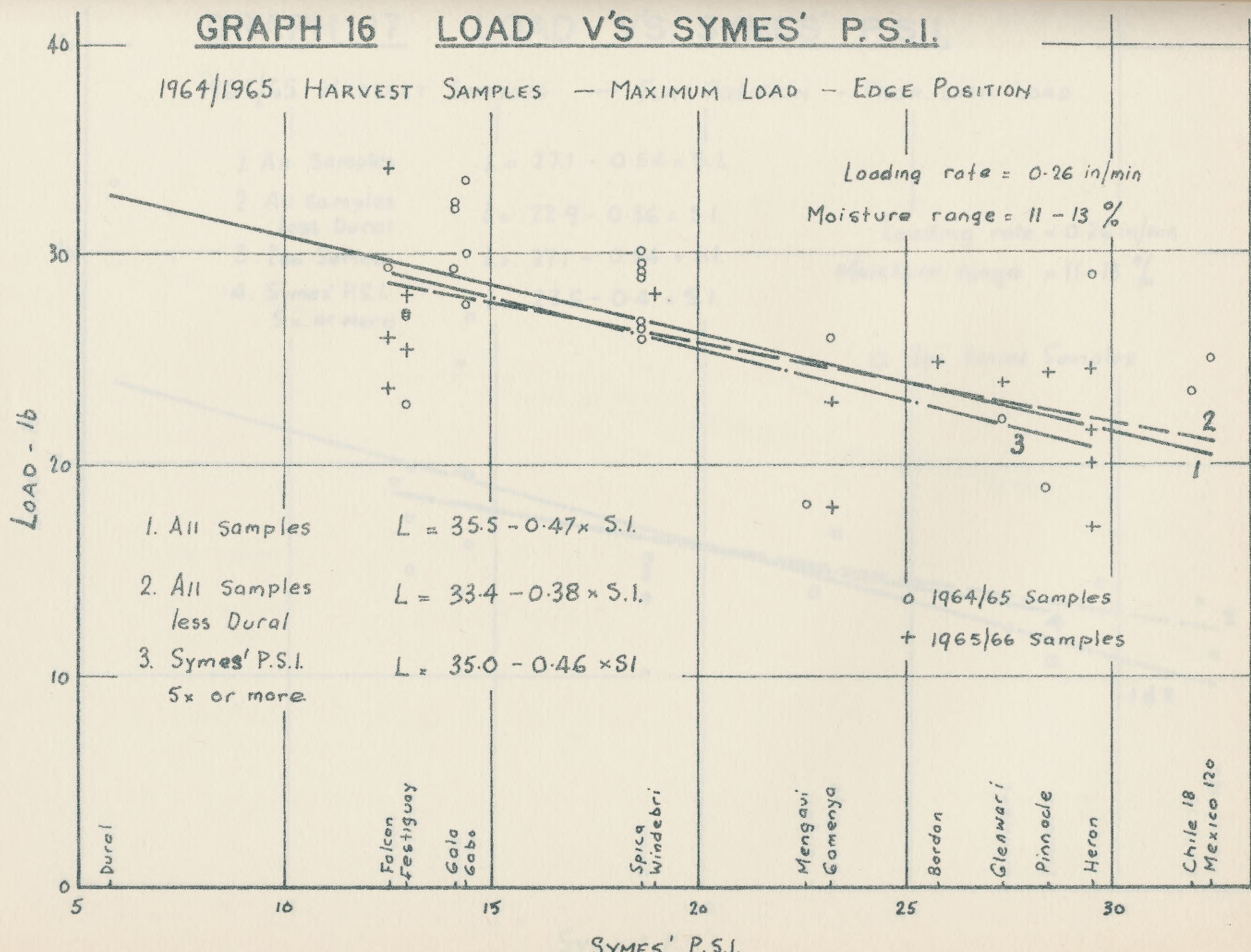

GRAPH 11 LOAD INDEX V'S SYMES' P.S.I.
1965/66 HARVEST SAMPLES – EDGE POSITION – PROP. LIMIT LOAD
Loading rate = 0·26 in/min
Moisture range = 11·5 – 12·5 %
LOAD INDEX x 5 - lb.
600
500
400
300
200
100
0
1
2
1. All Samples L.I. = 418 – 4·75 x S.I.
2. Symes' P.S.I. 5x or more L.I. = 388 – 3·82 x S.I.
Falcon
Festiguay
Windebri
Gamenya
Bordan
Glenwari
Pinnacle
Heron
5
10
15
20
25
30
SYMES' P.S.I.


GRAPH 12 LOAD INDEX V'S SYMES' P.S.I.
1965/66 HARVEST SAMPLES — EDGE POSITION – MAXIMUM LOAD.
Loading rate = 0·26 in./min.
Moisture range = 11·5 – 12·5 %
1. All Samples L.I. = 351 – 5·96 × S.I.
2. Symes' P.S.I. 5× or more L.I. = 342 – 5·70 × S.I.
Load Index – lb.
Symes' P.S.I.
Falcon
Festiguay
Windebri
Gamenya
Bordan
Glenwari
Pinnacle
Heron
0
100
200
300
400
500
600
5
10
15
20
25
30
1
2

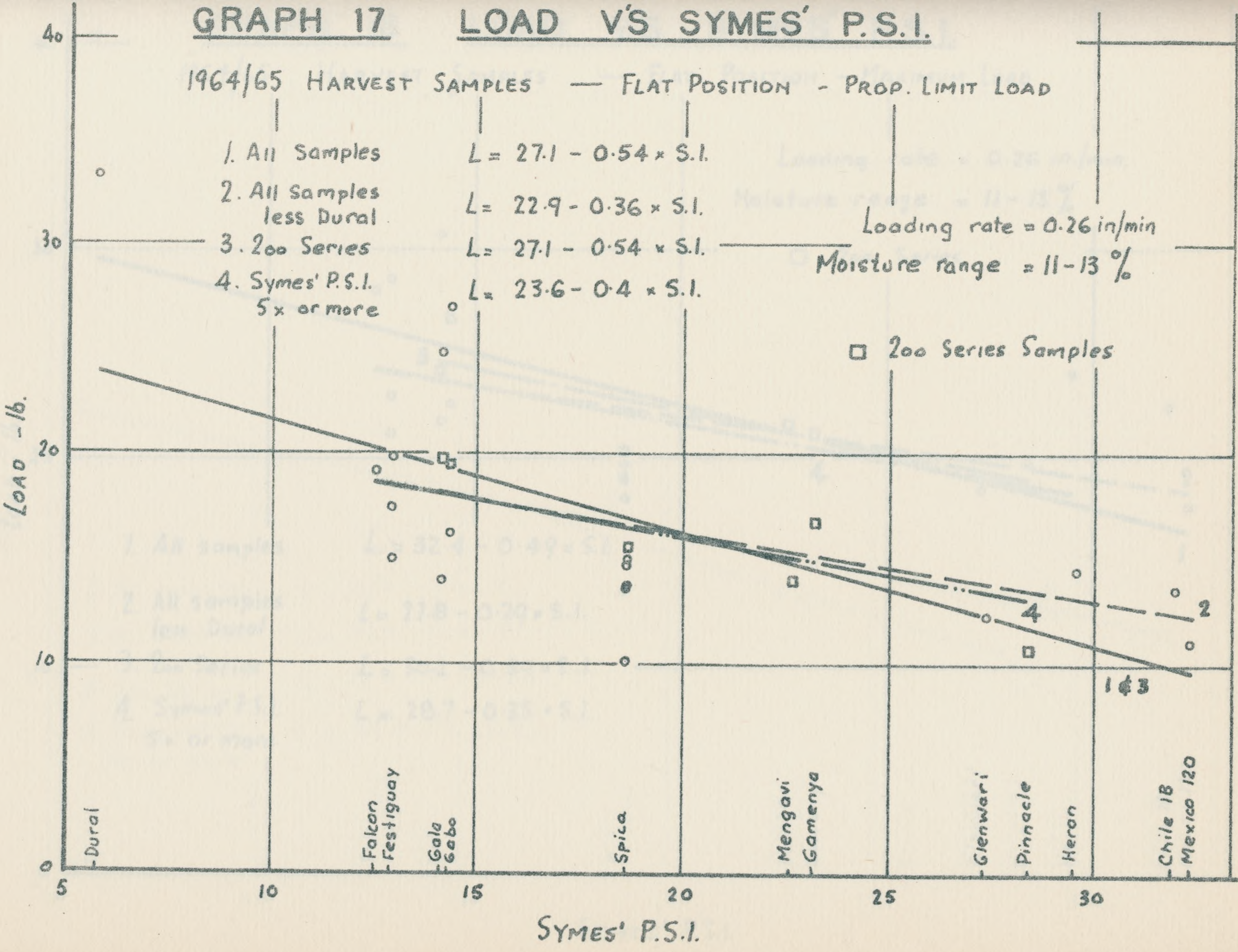

GRAPH 13 LOAD V'S SYMES' P.S.I.
1964/65 & 1965/66 HARVEST SAMPLES — FLAT POSITION - PROP. LIMIT LOAD.
1. All Samples L. = 25·9 - 0·52 × S.I.
2. All Samples less Dural L. = 22·8 - 0·39 × S.I.
3. Symes' P.S.I. 5× or more L. = 23·7 - 0·44 × S.I.
loading rate = 0·26 in/min.
Moisture range = 11 - 13 %
o 1964/65 Samples
+ 1965/66 Samples
LOAD - lb.
Dural
Falcon
Festiguay
Gala
Gabo
Spica
Windebri
Mengavi
Gamenya
Bordan
Glenwari
Pinnacle
Heron
Chile 1B
Mexico 120
Symes' P.S.I.

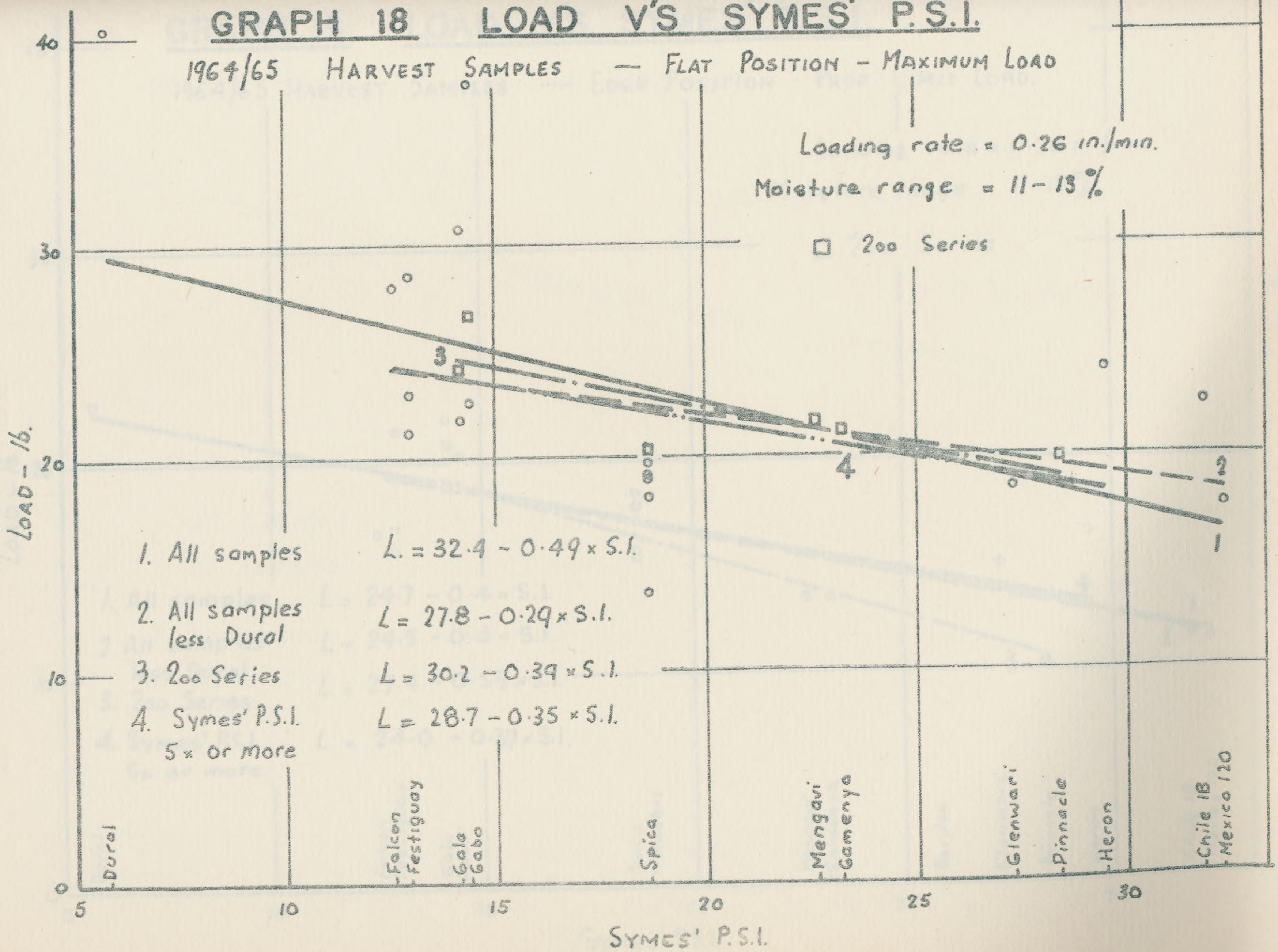

GRAPH 14 LOAD V'S SYMES' P.S.I.
1964/65 & 1965/66 HARVEST SAMPLES — FLAT POSITION - MAXIMUM LOAD
Loading rate = 0.26 in./min.
Moisture range = 11 - 13 %
o 1964/65 Samples
+ 1965/66 Samples
1. All samples L. = 30.7 - 0.42 × S.I.
2. All Samples less Dural L. = 27.3 - 0.27 × S.I.
3. Symes' P.S.I. 5x or more L. = 28.3 - 0.32 × S.I.
LOAD - lb.
SYMES' P.S.I.
Dural
Falcon
Festiguay
Gala
Gabo
Spica
Windebri
Mengavi
Gamenya
Bordan
Glenwari
Pinnacle
Heron
Chile 1B
Mexico 120

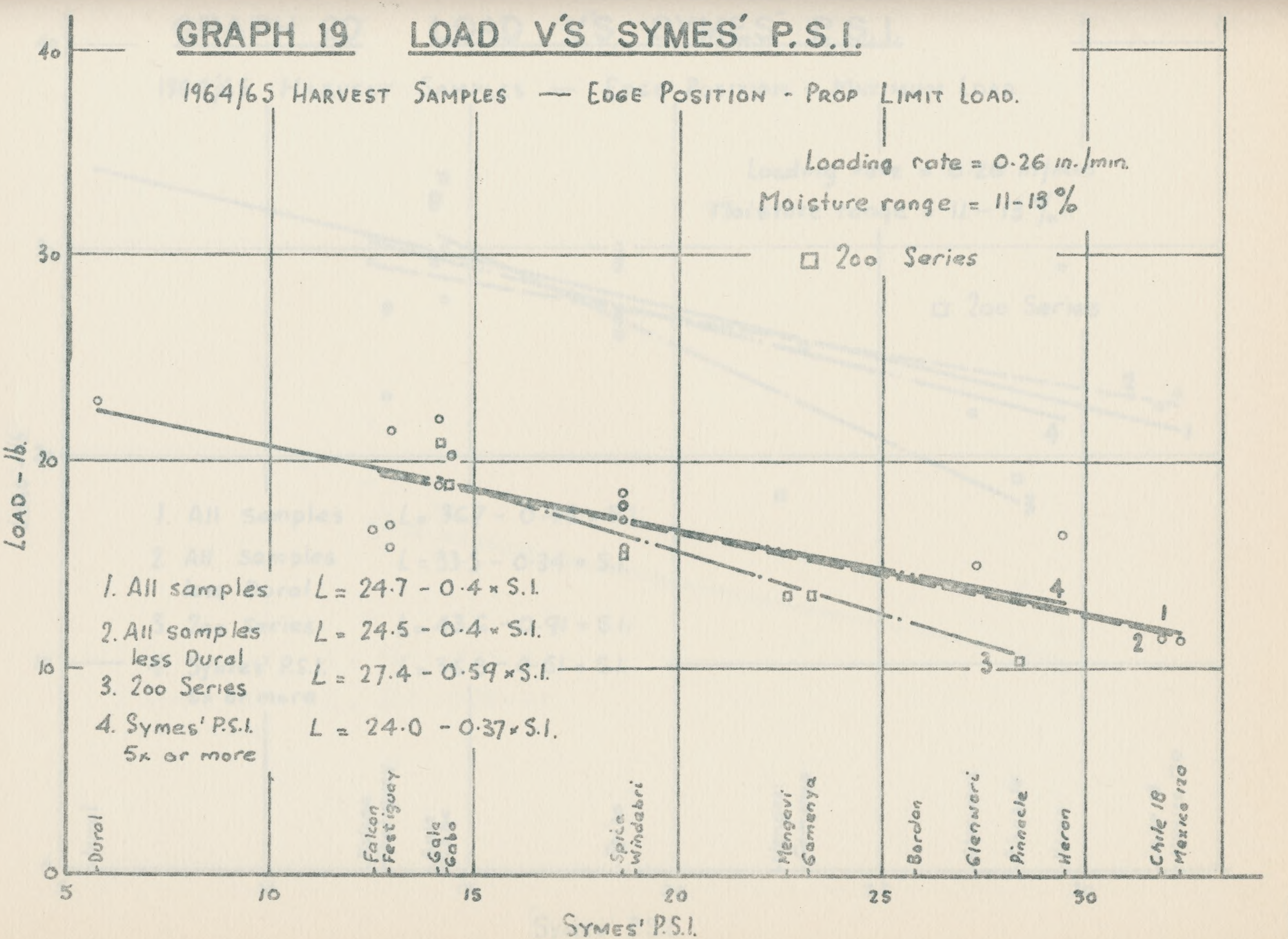

GRAPH 15 LOAD V'S SYMES' P.S.I.
1964/65 & 1965/66 HARVEST SAMPLES — EDGE POSITION - PROP. LIMIT LOAD.
1. All Samples L = 23.9 - 0.41 × S.I.
2. All Samples less Dural L = 23.6 - 0.4 × S.I.
3. Symes' P.S.I. 5× or more L = 23.9 - 0.41 × S.I.
Loading rate = 0.26 in./min.
Moisture range = 11 - 13 %
o 1964/65 Samples
+ 1965/66 Samples
1, 2 & 3
LOAD - lb.
0
10
20
30
40
5
15
25
SYMES' P.S.I.
Dural
Falcon
Festiguay
Gala
Gabo
Spica
Windebri
Mengavi
Gamenya
Bordan
Glenwari
Pinnacle
Heron
Chile 1B
Mexico 120

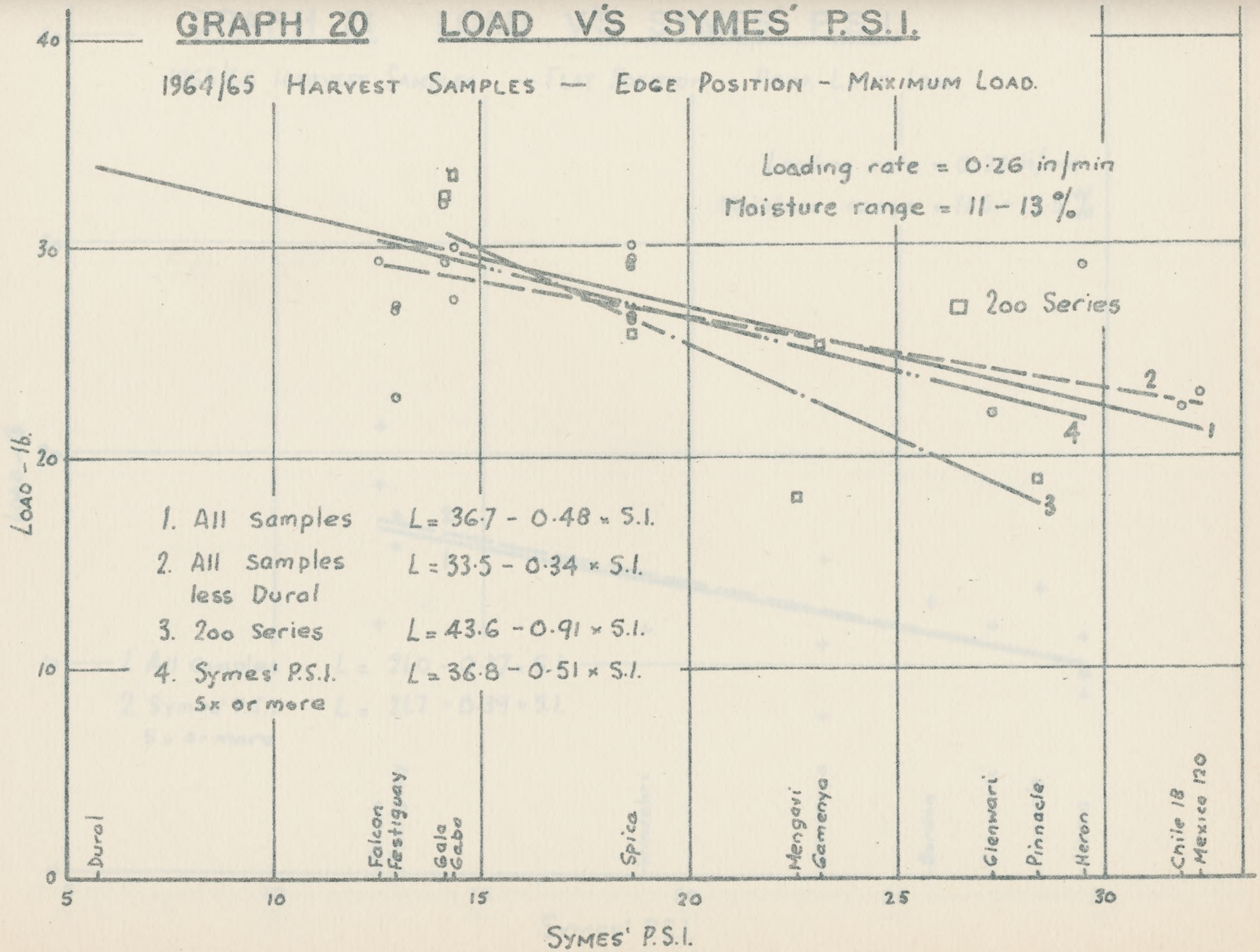


GRAPH 16 LOAD V'S SYMES' P.S.I.
1964/1965 HARVEST SAMPLES — MAXIMUM LOAD — EDGE POSITION
Loading rate = 0·26 in/min
Moisture range = 11 - 13 %
1. All samples L = 35·5 - 0·47 × S.I.
2. All samples less Dural L = 33·4 - 0·38 × S.I.
3. Symes' P.S.I. 5× or more L = 35·0 - 0·46 × SI
o 1964/65 Samples
+ 1965/66 Samples
LOAD - lb
SYMES' P.S.I.
0
10
20
30
40
5
10
15
20
25
30
1
2
3
Dural
Falcon
Festiguay
Gala
Gabo
Spica
Windebri
Mengavi
Gamenya
Bordan
Glenwari
Pinnacle
Heron
Chile 18
Mexico 120

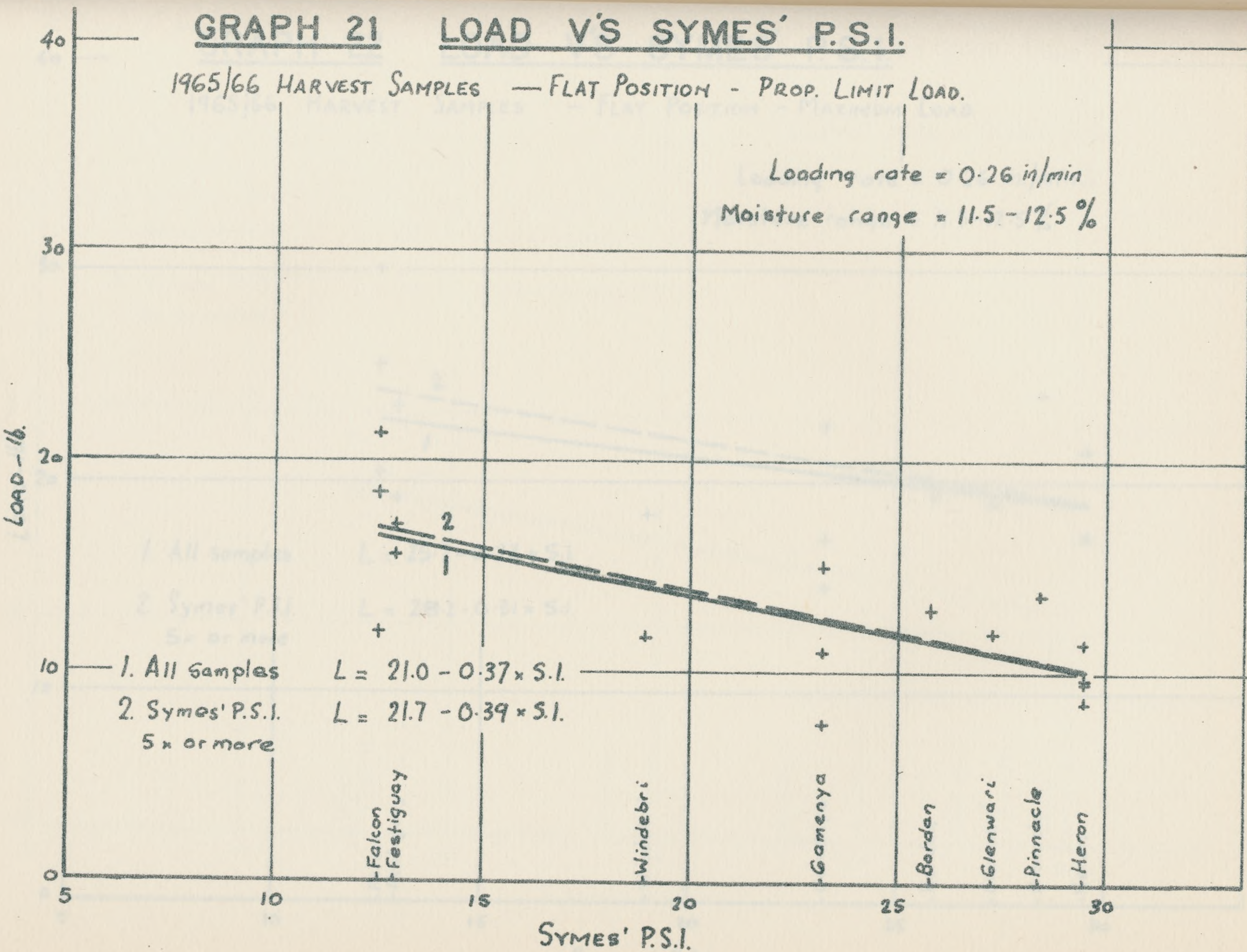

GRAPH 17 LOAD V'S SYMES' P.S.I.
1964/65 HARVEST SAMPLES — FLAT POSITION - PROP. LIMIT LOAD
1. All Samples L = 27.1 - 0.54 × S.I.
2. All Samples less Dural L = 22.9 - 0.36 × S.I.
3. 200 Series L = 27.1 - 0.54 × S.I.
4. Symes' P.S.I. 5× or more L = 23.6 - 0.4 × S.I.
Loading rate = 0.26 in/min
Moisture range = 11-13 %
200 Series Samples
LOAD - lb.
40
30
20
10
0
5
10
15
20
25
30
SYMES' P.S.I.
Dural
Falcon
Festiguay
Gala
Gabo
Spica
Mengavi
Gamenya
Glenwari
Pinnacle
Heron
Chile 1B
Mexico 120
1 & 3
2
4


GRAPH 18 LOAD V'S SYMES' P.S.I.
1964/65 HARVEST SAMPLES — FLAT POSITION - MAXIMUM LOAD
Loading rate = 0·26 in./min.
Moisture range = 11-13%
□ 200 Series
1. All samples L. = 32·4 - 0·49 × S.I.
2. All samples less Dural L = 27·8 - 0·29 × S.I.
3. 200 Series L = 30·2 - 0·39 × S.I.
4. Symes' P.S.I. 5× or more L = 28·7 - 0·35 × S.I.
LOAD - lb.
SYMES' P.S.I.
Dural
Falcon
Festiguay
Gala
Gabo
Spica
Mengavi
Gamenya
Glenwari
Pinnacle
Heron
Chile 1B
Mexico 120
0
10
20
30
40
5
10
15
20
25
30

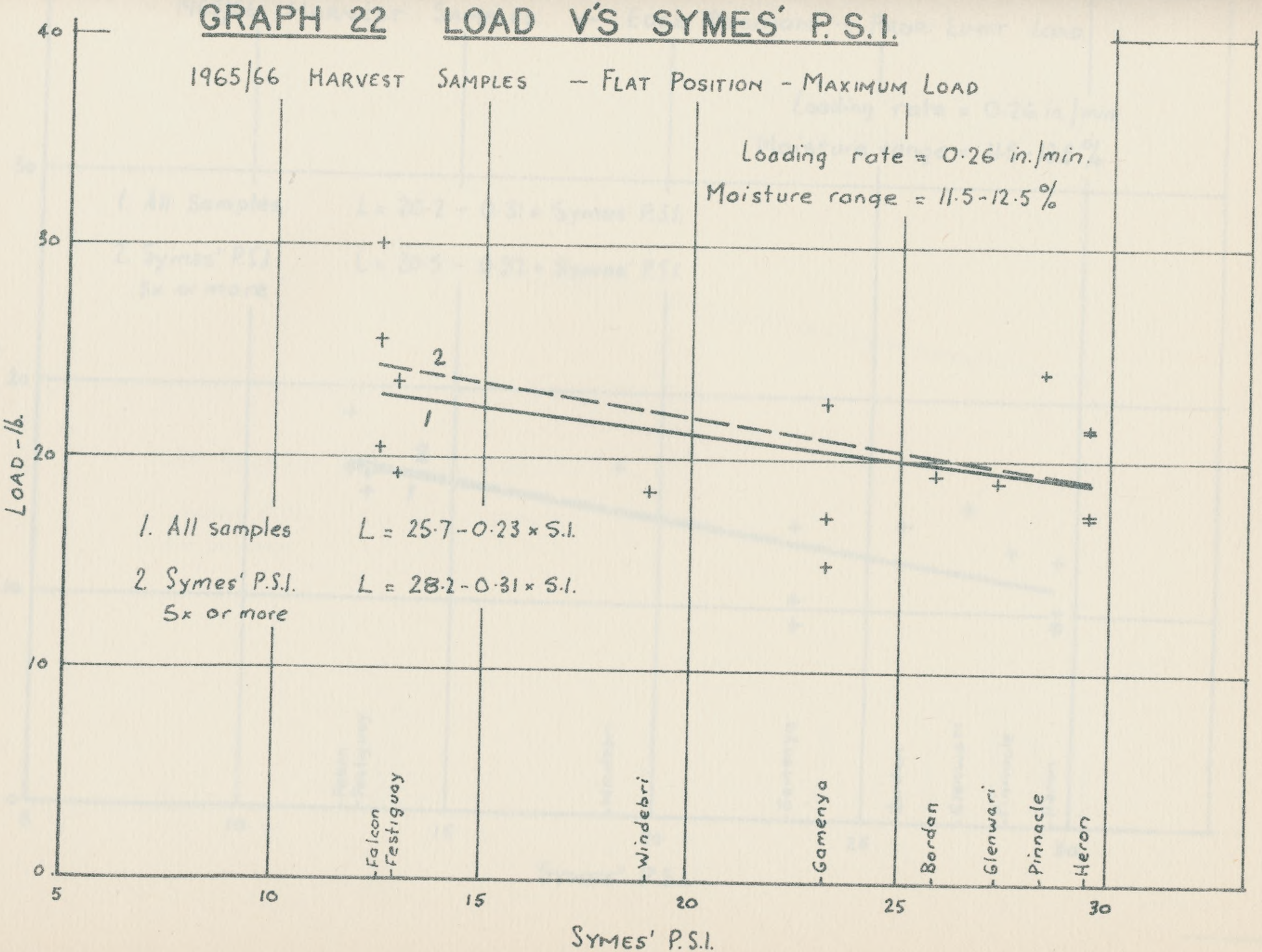

GRAPH 19 LOAD V'S SYMES' P.S.I.
1964/65 HARVEST SAMPLES — EDGE POSITION - PROP LIMIT LOAD.
Loading rate = 0·26 in./min.
Moisture range = 11-13 %
□ 200 Series
1. All samples L = 24·7 - 0·4 × S.I.
2. All samples less Dural L = 24·5 - 0·4 × S.I.
3. 200 Series L = 27·4 - 0·59 × S.I.
4. Symes' P.S.I. 5x or more L = 24·0 - 0·37 × S.I.
LOAD - lb.
SYMES' P.S.I.
Dural
Falcon
Festiguay
Gala
Gabo
Spica
Windebri
Mengavi
Gamenya
Bordan
Glenwari
Pinnacle
Heron
Chile 1B
Mexico 120
0
10
20
30
40
5
15
25
1
2
3
4



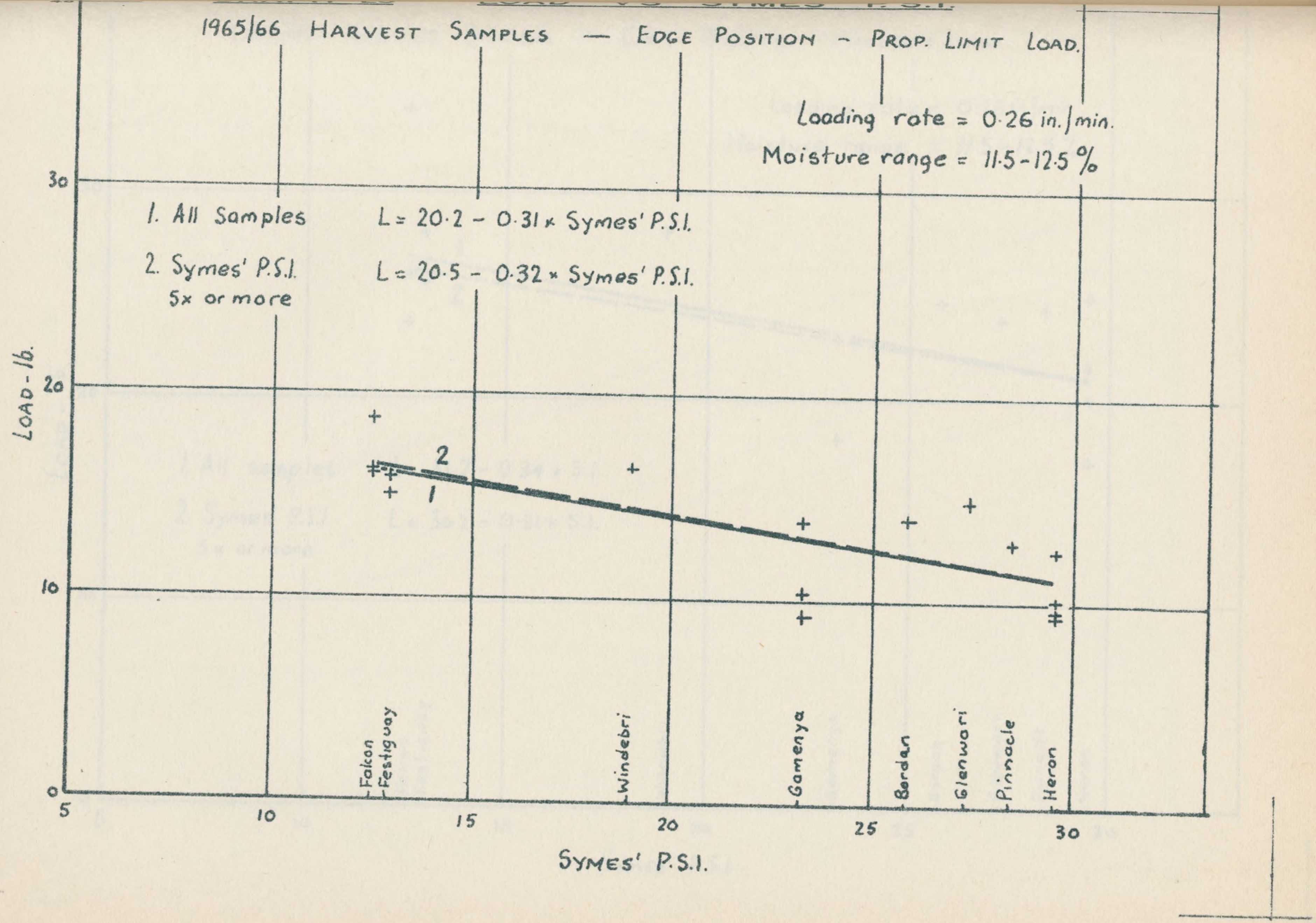
GRAPH 20 LOAD V'S SYMES' P.S.I.
1964/65 HARVEST SAMPLES — EDGE POSITION - MAXIMUM LOAD.
Loading rate = 0·26 in/min
Moisture range = 11 - 13 %
□ 200 Series
1. All samples L = 36·7 - 0·48 × S.I.
2. All samples less Dural L = 33·5 - 0·34 × S.I.
3. 200 Series L = 43·6 - 0·91 × S.I.
4. Symes' P.S.I. 5x or more L = 36·8 - 0·51 × S.I.
LOAD - lb.
SYMES' P.S.I.
Dural
Falcon
Festiguay
Gala
Gabo
Spica
Mengavi
Gamenya
Glenwari
Pinnacle
Heron
Chile 18
Mexico 120

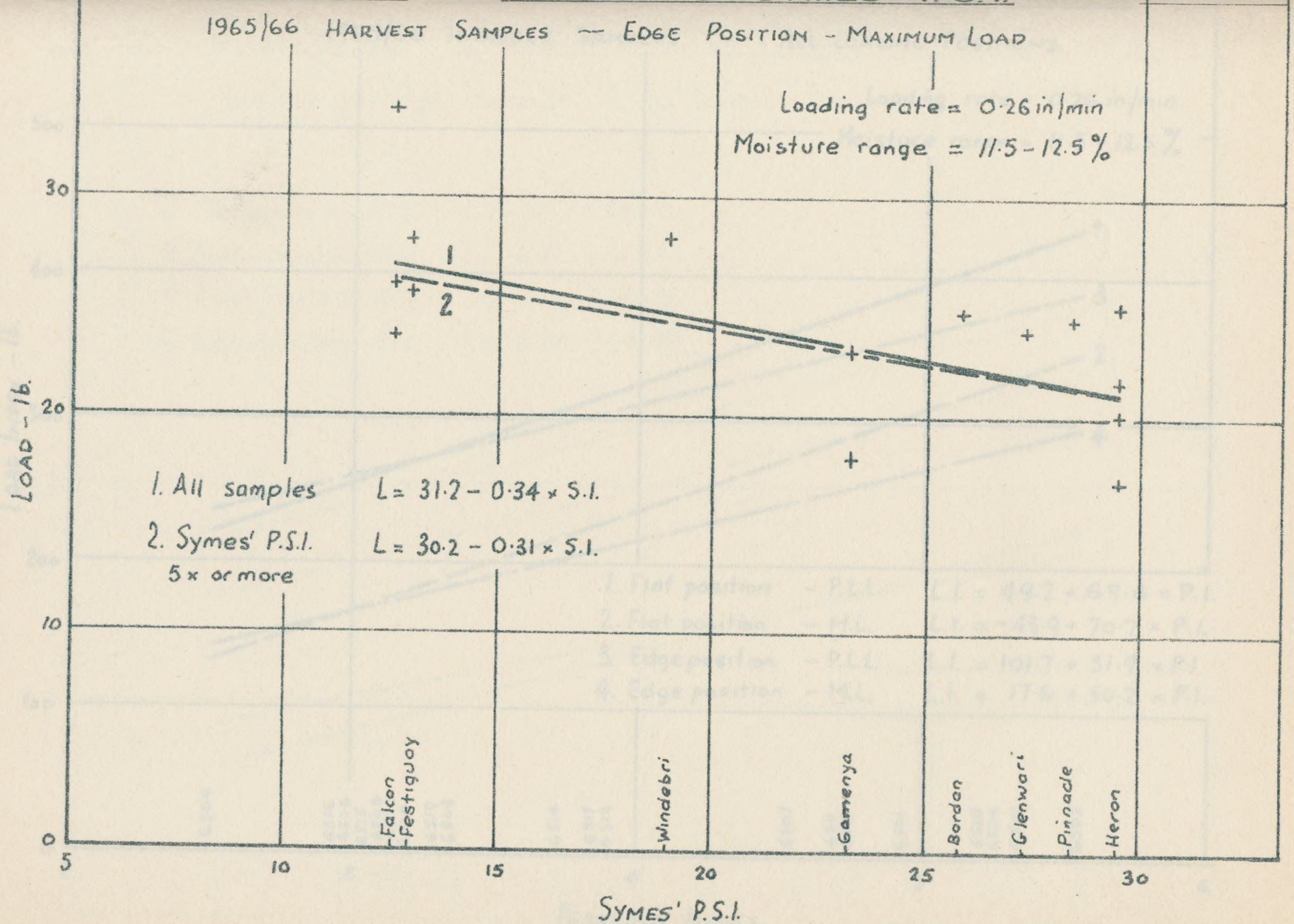


GRAPH 21 LOAD V'S SYMES' P.S.I.
1965/66 HARVEST SAMPLES — FLAT POSITION - PROP. LIMIT LOAD.
Loading rate = 0·26 in/min
Moisture range = 11·5 - 12·5 %
1. All samples L = 21.0 - 0.37 × S.I.
2. Symes' P.S.I. L = 21.7 - 0.39 × S.I.
5 × or more
2
1
Falcon
Festiguay
Windebri
Gamenya
Bordan
Glenwari
Pinnacle
Heron
LOAD - lb.
SYMES' P.S.I.
0
10
20
30
40
5
10
15
20
25
30



GRAPH 22 LOAD V'S SYMES' P.S.I.
1965/66 HARVEST SAMPLES — FLAT POSITION - MAXIMUM LOAD
Loading rate = 0·26 in./min.
Moisture range = 11·5-12·5 %
1. All samples L = 25·7-0·23 × S.I.
2. Symes' P.S.I. 5× or more L = 28·2-0·31 × S.I.
LOAD - lb.
SYMES' P.S.I.
40
30
20
10
0
5
10
15
20
25
30
Falcon
Festiguay
Windebri
Gamenya
Bordan
Glenwari
Pinnacle
Heron
1
2

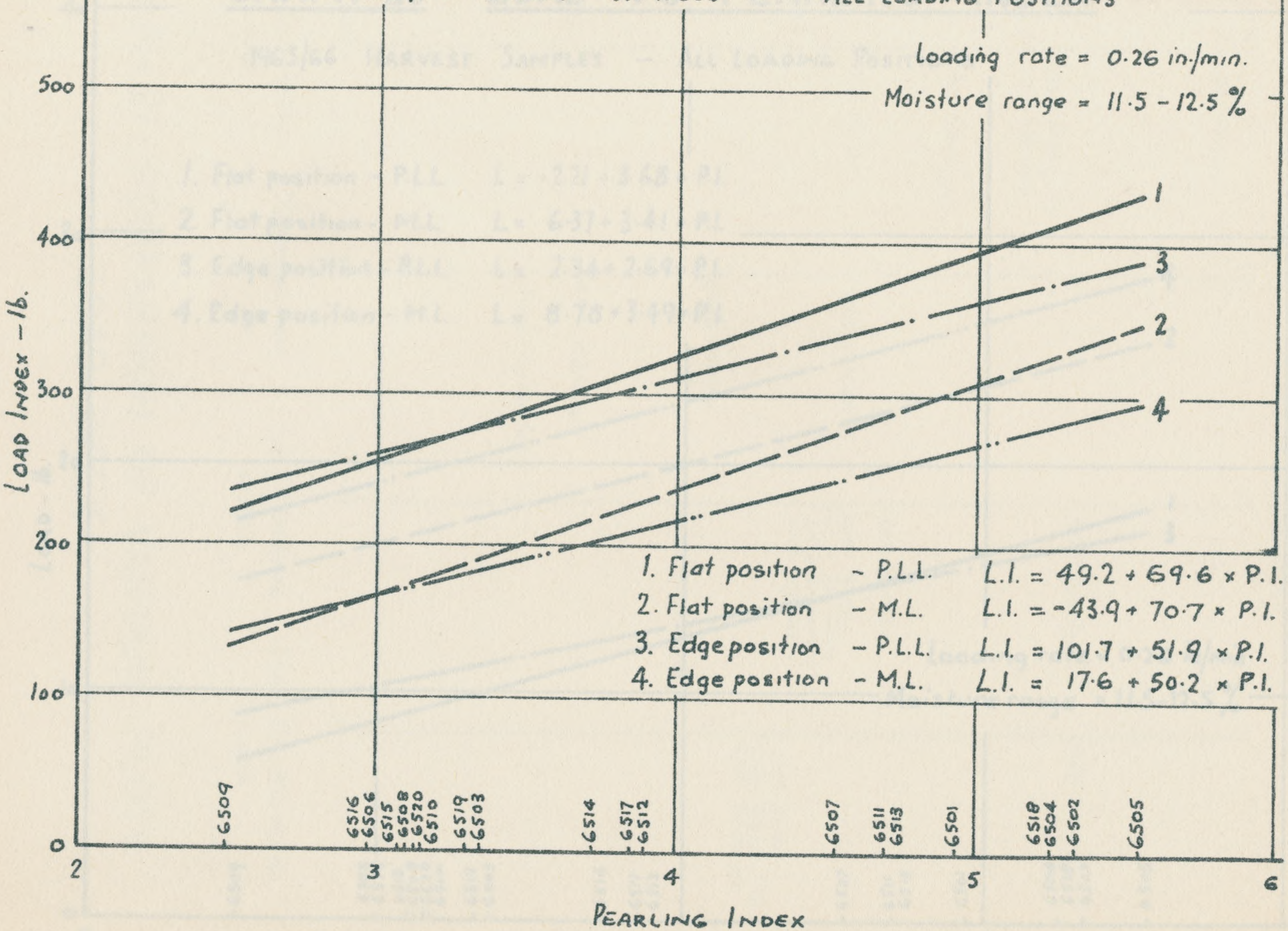

1965/66 HARVEST SAMPLES — EDGE POSITION — PROP. LIMIT LOAD.
Loading rate = 0·26 in./min.
Moisture range = 11·5 - 12·5 %
1. All Samples L = 20·2 - 0·31 × Symes' P.S.I.
2. Symes' P.S.I. 5x or more L = 20·5 - 0·32 × Symes' P.S.I.
LOAD - lb.
SYMES' P.S.I.
0
10
20
30
5
10
15
20
25
30
2
1
Falcon
Festiguay
Windebri
Gamenya
Bordan
Glenwari
Pinnacle
Heron

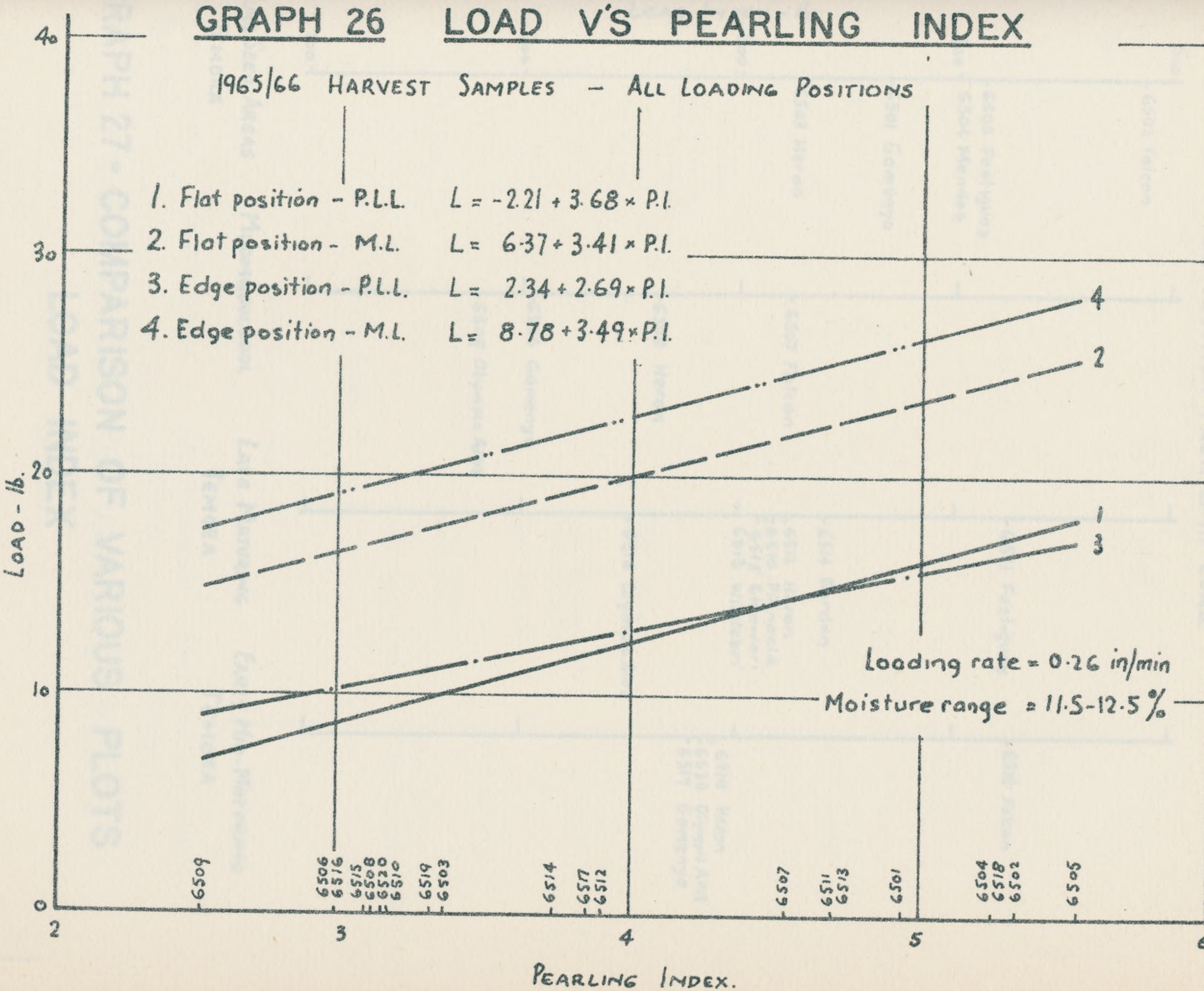


1965/66 HARVEST SAMPLES — EDGE POSITION - MAXIMUM LOAD
Loading rate = 0·26 in/min
Moisture range = 11·5 - 12·5 %
1
2
1. All samples L = 31·2 - 0·34 × S.I.
2. Symes' P.S.I. 5 × or more L = 30·2 - 0·31 × S.I.
LOAD - lb.
30
20
10
0
5
10
15
20
25
30
Falcon
Festiguay
Windebri
Gamenya
Bordan
Glenwari
Pinnacle
Heron
SYMES' P.S.I.

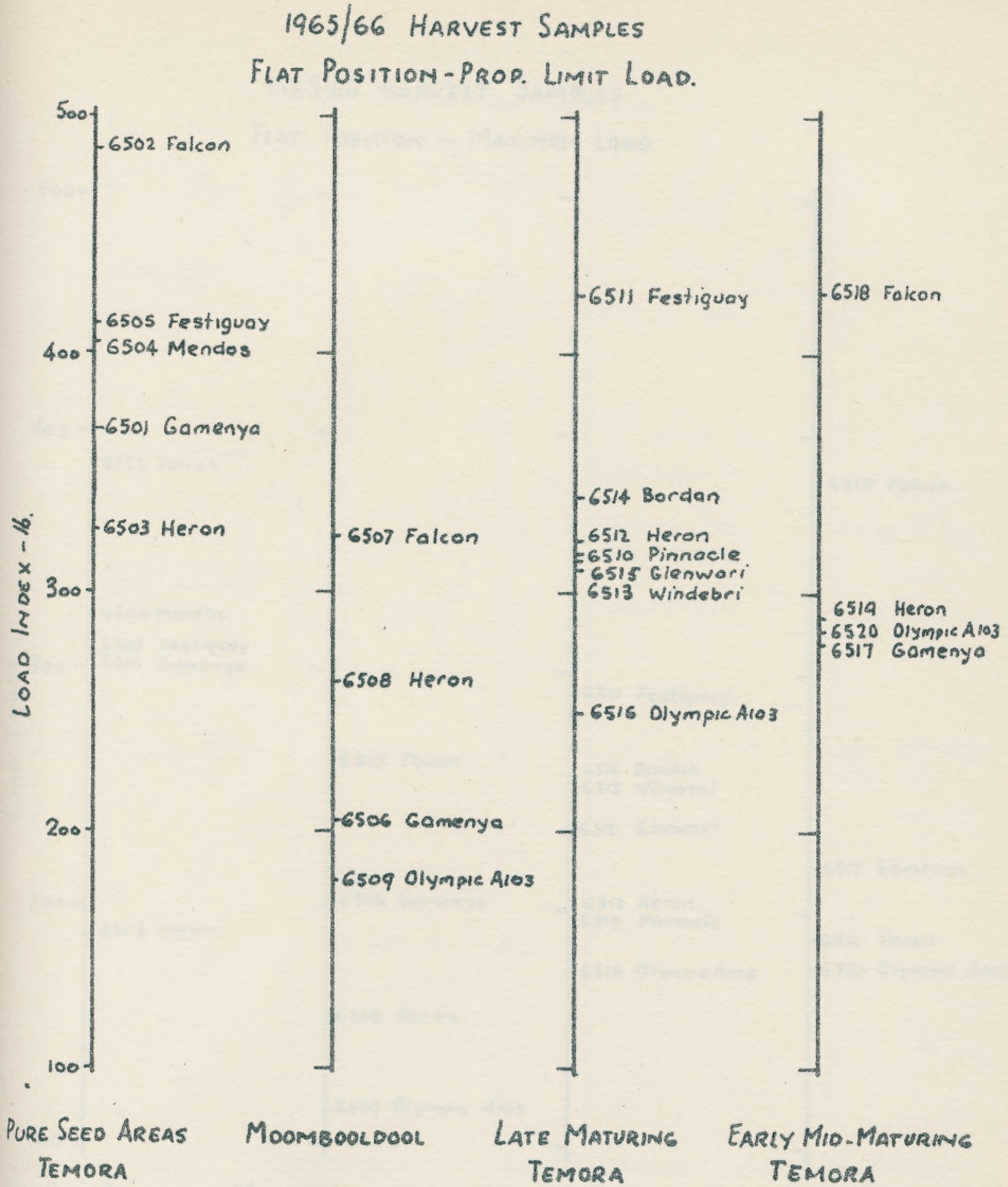
GRAPH 25 LOAD INDEX VS PEARLING INDEX

1965/66 HARVEST SAMPLES – ALL LOADING POSITIONS

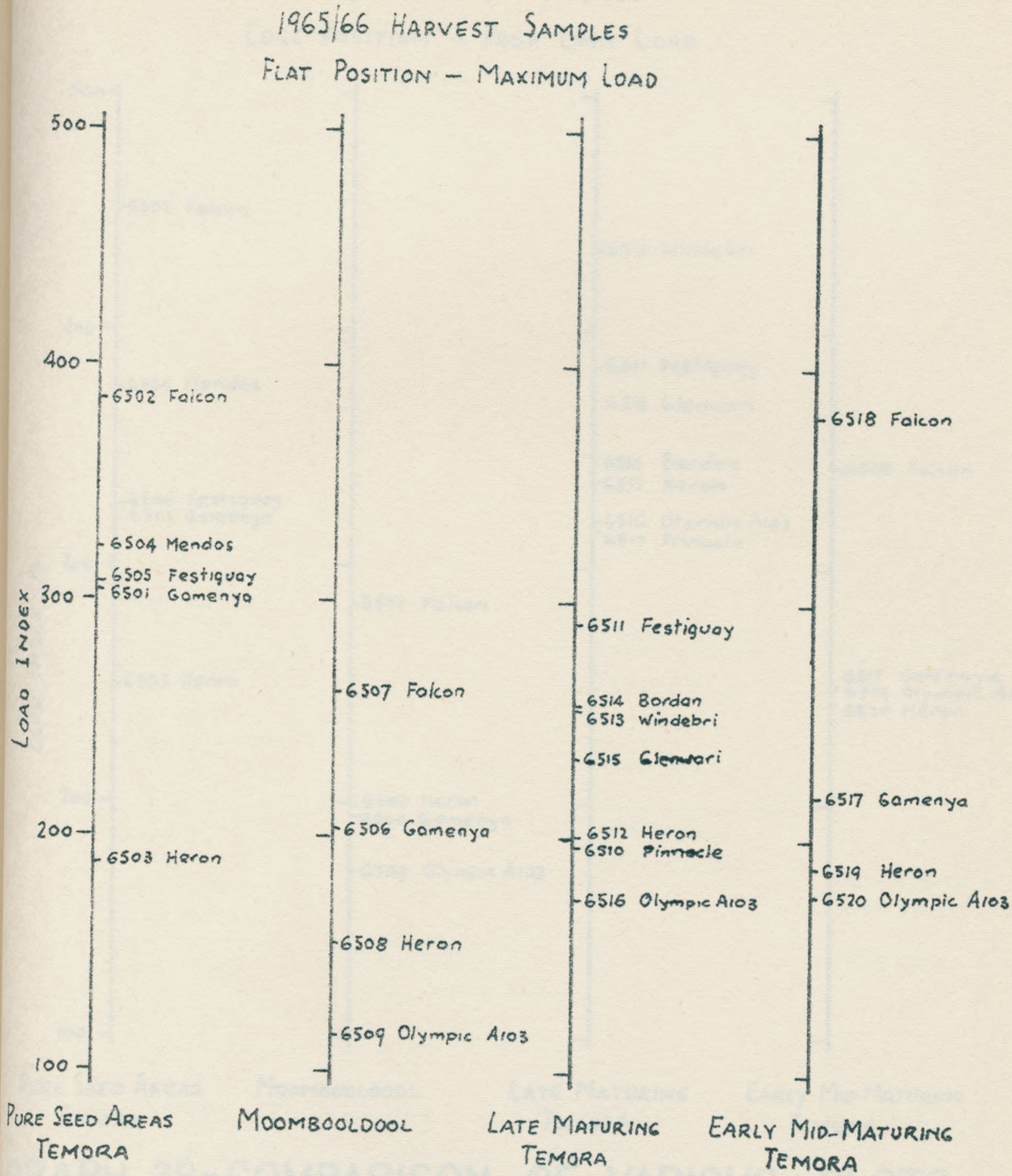




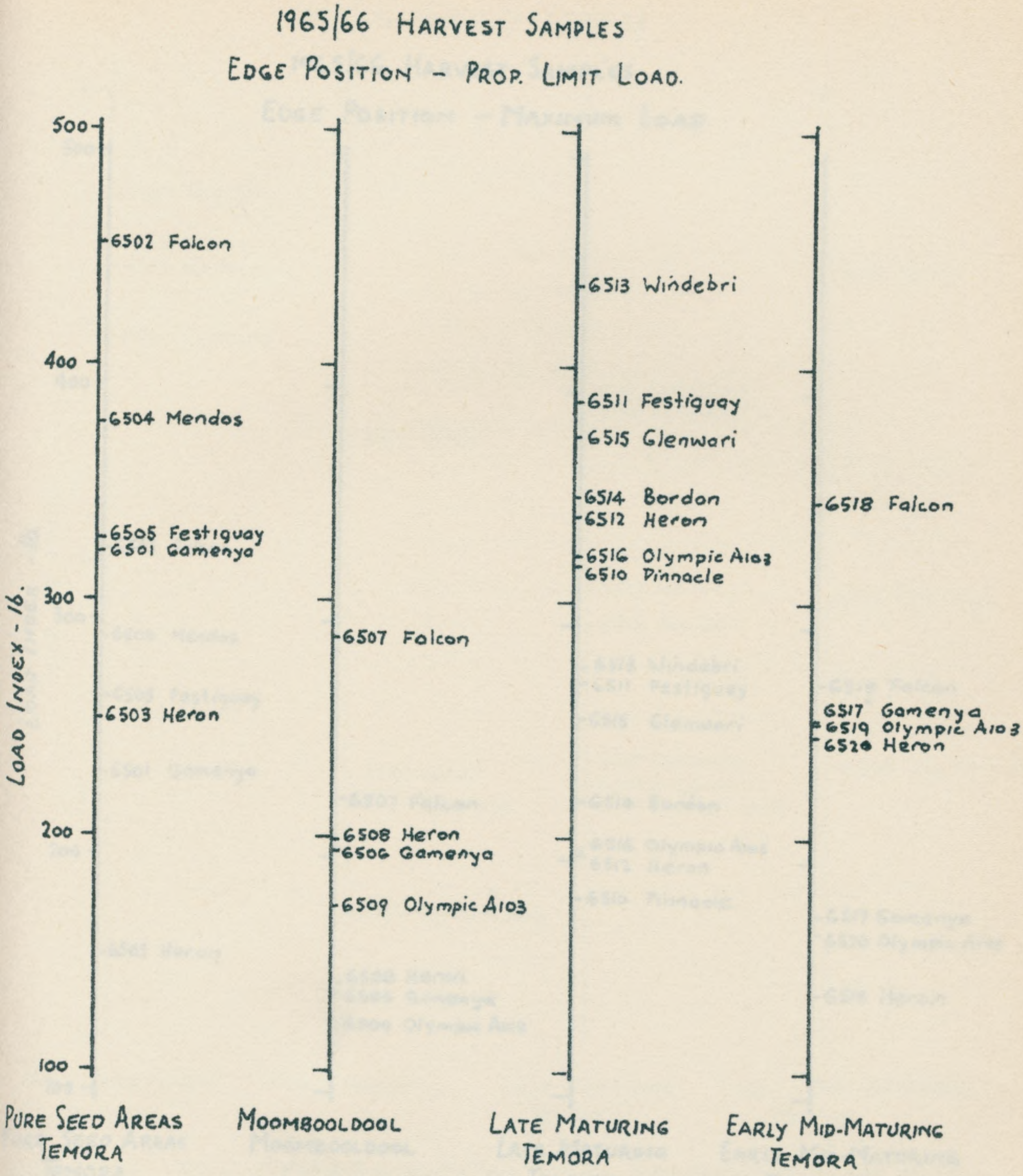
GRAPH 26 LOAD V'S PEARLING INDEX
1965/66 HARVEST SAMPLES - ALL LOADING POSITIONS
1. Flat position - P.L.L. L = -2.21 + 3.68 × P.I.
2. Flat position - M.L. L = 6.37 + 3.41 × P.I.
3. Edge position - P.L.L. L = 2.34 + 2.69 × P.I.
4. Edge position - M.L. L = 8.78 + 3.49 × P.I.
Loading rate = 0.26 in/min
Moisture range = 11.5-12.5 %
LOAD - lb.
PEARLING INDEX.
0
10
20
30
40
2
3
4
5
6
1
2
3
4
6509
6506
6516
6515
6508
6520
6510
6519
6503
6514
6517
6512
6507
6511
6513
6501
6504
6518
6502
6505



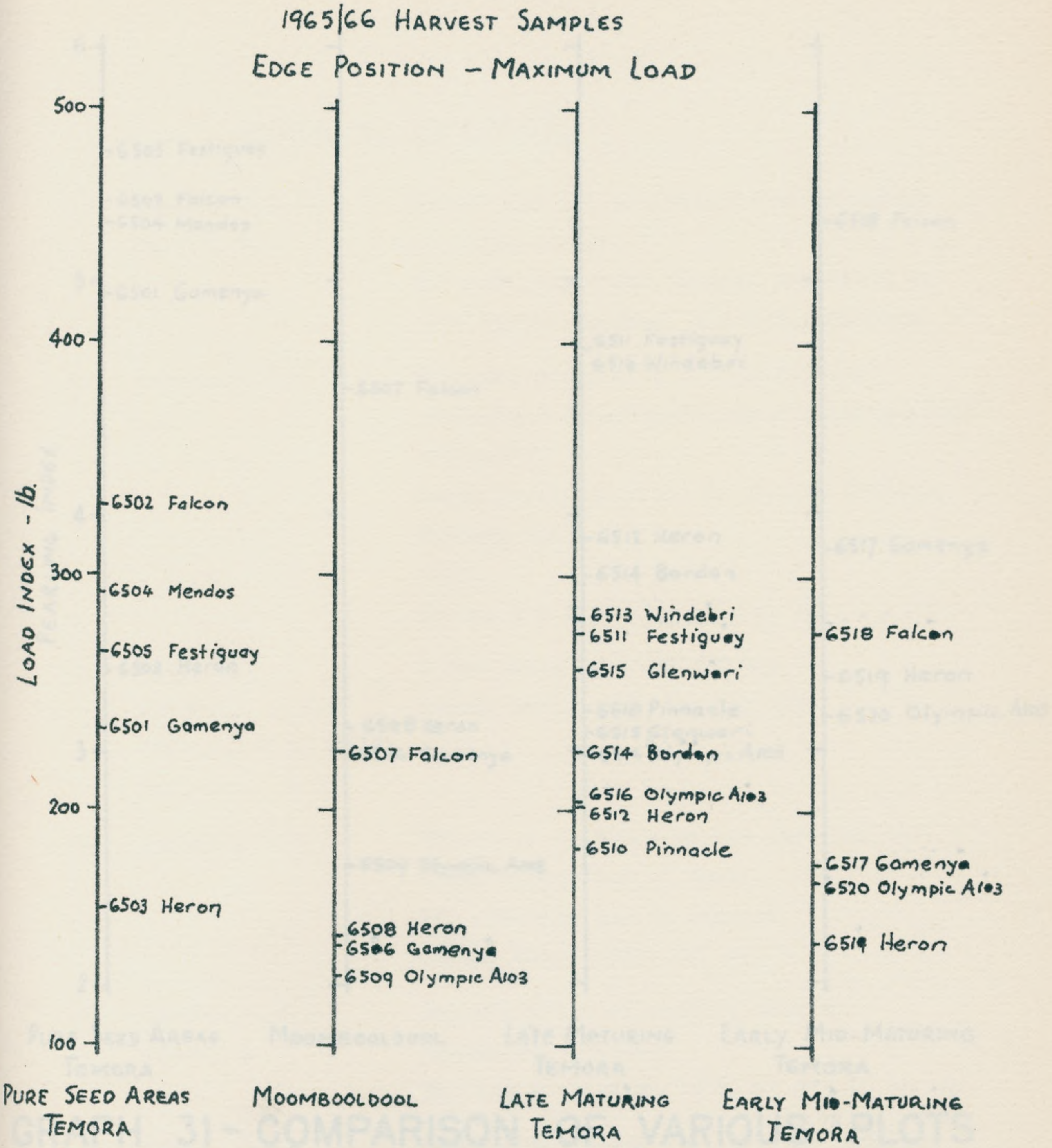
GRAPH 27 - COMPARISON OF VARIOUS PLOTS
LOAD INDEX



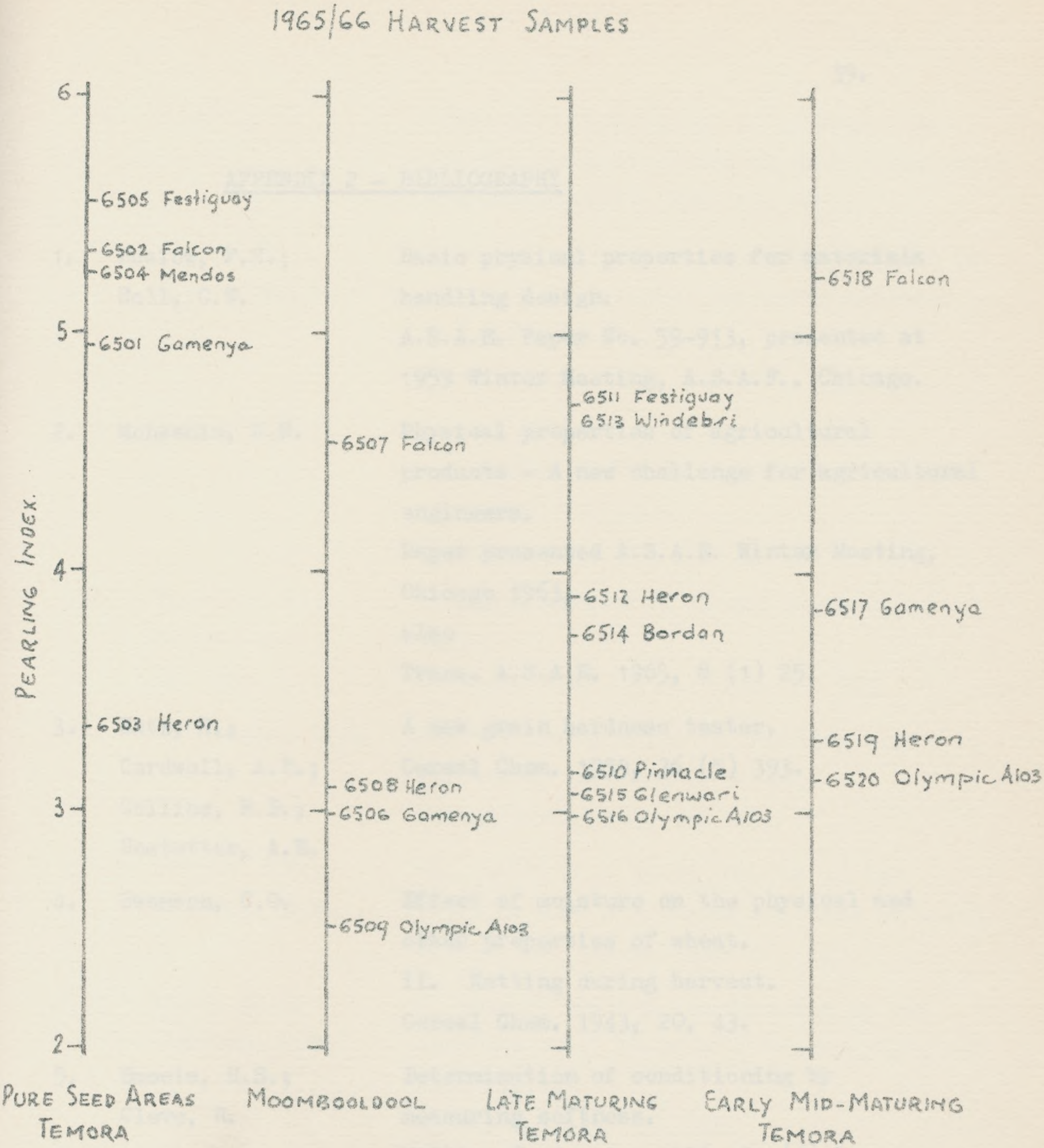
GRAPH 28-COMPARISON OF VARIOUS PLOTS
LOAD INDEX



GRAPH 29 - COMPARISON OF VARIOUS PLOTS LOAD INDEX



GRAPH 30 - COMPARISON OF VARIOUS PLOTS
LOAD INDEX



GRAPH 31 - COMPARISON OF VARIOUS PLOTS
PEARLING INDEX

APPENDIX 2 - BIBLIOGRAPHY

1.	Buelow, F.H.; Hall, C.W.	Basic physical properties for materials handling design. A.S.A.E. Paper No. 59-913, presented at 1959 Winter Meeting, A.S.A.F., Chicago.
2.	Mohsenin, N.N.	Physical properties of agricultural products - A new challenge for agricultural engineers. Paper presented A.S.A.E. Winter Meeting, Chicago 1963, also Trans. A.S.A.E. 1965, 8 (1) 25.
3.	Katz, R.; Cardwell, A.B.; Collins, N.D.; Hostetter, A.E.	A new grain hardness tester. Cereal Chem. 1959, 36 (5) 393.
4.	Swanson, C.O.	Effect of moisture on the physical and other properties of wheat. II. Wetting during harvest. Cereal Chem. 1943, 20, 43.
5.	Smeets, H.S.; Cleve, H.	Determination of conditioning by measuring softness. Milling Production 1956, 21 (4) 5.
6.	Grosh, G.M.; Milner, M.	Water penetration and internal cracking in tempered wheat grains. Cereal Chem. 1959, 36, 260.

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1.	Buelow, F.H.; Hall, C.W.	Basic physical properties for materials handling design. A.S.A.E. Paper No. 59-913, presented at 1959 Winter Meeting, A.S.A.F., Chicago.
2.	Mohsenin, N.N.	Physical properties of agricultural products - A new challenge for agricultural engineers. Paper presented A.S.A.E. Winter Meeting, Chicago 1963, also Trans. A.S.A.E. 1965, 8 (1) 25.
3.	Katz, R.; Cardwell, A.B.; Collins, N.D.; Hostetter, A.E.	A new grain hardness tester. Cereal Chem. 1959, 36 (5) 393.
4.	Swanson, C.O.	Effect of moisture on the physical and other properties of wheat. II. Wetting during harvest. Cereal Chem. 1943, 20, 43.
5.	Smeets, H.S.; Cleve, H.	Determination of conditioning by measuring softness. Milling Production 1956, 21 (4) 5.
6.	Grosh, G.M.; Milner, M.	Water penetration and internal cracking in tempered wheat grains. Cereal Chem. 1959, 36, 260.

7. Paukner, E. — (Objective measurement of softness for determination of degree of malt solubility) Brauwissenschaft 1951, 11, 187.

8. Milner, M.; Shellenberger, J.A. — Physical properties of weathered wheat in relation to internal fissuring detected radiographically. Cereal Chem. 1953, 30, 202.

9. Bennett, E. H. — Kernel hardness in corn 1. A machine for the rapid determination of kernel hardness. Cereal Chem. 1950, 27 (5) 222.

10. Taylor, J.W.; Bayles, B.B.; Fifield, C.C. — A simple measure of kernel hardness in wheat. J. Amer. Soc. Agron. 1939, 31, 775.

11. McCluggage, M.E. — Factors influencing the pearling test for kernel hardness in wheat. Cereal Chem. 1943, 20, 686.

12. Kramer, H.H.; Albrecht, H.R. — The adaption to small samples of the pearling test for kernel hardness in wheat. J. Am. Soc. Agron. 1948, 40, 422.

13. Beard, B.H., Poehlman, J.M. — A study of quality, as measured by the pearling test, in crosses between hard and soft wheats. Agron. J. 1954, 46, 220.

14. Symes, K.J. — Classification of Australian wheat varieties, based on the granularity of their wholemeal. Aust. J. Exp. Agric. Anim. Husb. 1961, 1, 18.

15.	Cutler, G.H.; Brinson, G.A.	The granulation of whole meal and a method of expressing it numerically. Cereal Chem. 1935, 12, 120.
16.	Worzella, W.W.; Cutler, G.H.	A critical study of technique for measuring granulation in wheat meal. J. Agric. Res. 1939, 58, 329.
17.	Barmore, M.A.; Seeborg, E.F.; Bresson, C.R.; Lewis, O.J.; Flay, F.A.; Weeks, C.C.	Quality characteristics of wheat grown in the western region in 1952. Western Wheat Quality Lab., Pullman, Washington, 1953, 1, (Mimeo).
18.	Berg, S.O.	Is the degree of grittiness of wheat flour mainly a varietal character? Cereal Chem. 1947, 24, 274.
19.	Fajersson, F.	(The micro-method of Berg for determining the degree of grittiness of flour from different varieties of wheat.) Agri. Hortique Genetica, Landskrona 1950, 8, 109.
20.	Fajersson, F.	(The grittiness of wheaten flour as a problem of plant cultivation.) Agri. Hortique Genetica, Landskrona 1953, 11, 149.
21.	Fajersson, F.	(Studies of the grittiness value (fine flour index) of different varieties of wheat at finer and coarser milling of the grain.) Agri. Hortique Genetica, Landskrona 1956, 14, 60.

22.	Greer, E.N.	The milling and baking properties of home grown winter wheat 1947-1949. J. Nat. Inst. Agric. Bot. 1950, 5, 459.
23.	Greer, E.N.; Hinton, J.J.C.	The two types of wheat endosperm. Nature 1950, 165, 746.
24.	Greer, E.N.; Hinton, J.J.C.; Jones, C.R.; Kent, N.L.	The occurrence of endosperm cells in wheat flour. Cereal Chem. 1951, 28, 58.
25.	Symes, K.J.	The inheritance of grain hardness in wheat as measured by the particle size index. Aust. J. Agric. Res. 1965, 16 (2) 113.
26.	Roberts, H.F.	A quantitative method for the determination of hardness in wheat. Kans. Agr. Expt. Sta. Bul. 167, 1910, 371.
27.	Jelinck, J.	Apparatus for the determination of hardness of the kernel. First International Conference on Breadstuffs, Prague, 1927.
28.	Shpolyanskaya, A.L.	(Structural-mechanical properties of the wheat grain). Kolloid, Zh., 1952, 14 (1) 137.
29.	Zoerb, G.C.	Mechanical and rheological properties of grain. Ph.D. Thesis, Mich. Univ. 1958. (unpublished).

30.	Bilanski, W.K.	Breaking strength of seed grains. Paper presented Annual Meeting Canad. S.A.E., Ottawa, June, 1962.
31.	Mitchell, F.S.; Rounthwaite, T.E.	Resistance of two varieties of wheat to mechanical damage by impact. J. Agric. Engng. Res. 1964, 9 (4) 303.
32.	Arnold, P.C.; Roberts, A.W.	Stress distributions in loaded wheat grains. J. Agric. Engng. Res. 1966, 11 (1) 38.
33.	Mohsenin, N.N.	A testing machine for the determination of mechanical and rheological properties of agricultural products. Penna. Agric. Exp. Sta. Bull. 701, 1963.
34.	Symes, K.J.	The particle size index of a number of wheat varieties. 19-8-64, Mimeo.
35.	Moroney, M.J.	Facts from figures. Third Edn. 1956, Pelican.
36.	Brownlee, K.A.	Industrial experimentation 4th Edn. 1949, H.M.S.O.
37.	Dixon, W.J.; Massey, F.J.	Introduction to statistical analysis. 1951, McGraw-Hill.
38.	Brown, C. Walk-den.	Wheat varieties for 1959. Agric. Gazette 1959, 70 (2) 85.
39.	Brown, C. Walk-den; Fitzsimmons, R.W.	Wheat Varieties for 1966. Agric. Gazette 1966, 77 (1) 2.
40.	Symes, K.J.	Identification of wheat varieties from their grain characters. Agric. Gazette 1958, 69, 178.

APPENDIX 3.

PHYSICAL AND MECHANICAL PROPERTIES OF

AGRICULTURAL PRODUCTS

ABSTRACTS OF PAPERS

NOTE : It is not intended that these abstracts represent a complete coverage of the subject suggested by the above heading. The bibliographics of many of the papers mentioned list further papers which may be of interest. It is felt, however, that the literature cited here gives a general coverage of the areas where research relating to the above subject has been performed.

ALMGREN, G.

A grid for counting 1,000 grains.

Agric. Gazette of N.S.W. 1964, 75 (9) 1298.

The weight of 1,000 grains of wheat, considered with bushel weight and moisture content, provides indirect information about grain size and density.

To relieve the problem of counting the grains, a simple and cheap grid has been designed. Details of construction are presented together with a suitable method for its use. Approximately 1 to 1½ minutes are required to measure a 1,000 grain weight.

ARNOLD, P.C.; ROBERTS, A.W.

Stress distributions in loaded wheat grains.
J. Agric. Engng. Res. 1966, 11 (1) 38.

For the purpose of understanding the way in which wheat grains are able to withstand the loads to which they are subjected during mechanical handling by conveying and processing equipment, it is necessary to have some knowledge of the stress distributions throughout the grain. For light load conditions it is shown that the stresses can be analysed on the basis of elasticity theory employing the Hertz stress analysis. As the loads are increased up to the point of failure the stress distribution is rather complex and difficult to analyse theoretically. It is shown that with the aid of photo-elastic model studies in conjunction with microscopic deformation investigations on actual grains a qualitative analysis is possible. By means of this technique a better understanding of the mechanism of failure is obtained.

BENNETT, EDMOND H.

Kernel hardness in corn
I. A machine for the rapid determination of kernel hardness.
Cereal Chem. 1950, 27 (5) 222.

An electrically operated machine was devised for the rapid determination of hardness of grain. A mechanical feeder delivered grain at a uniform rate between an inner driven wheel rotated at 33 r.p.m. and an outer wheel which rotated only when grain was being crushed, since it was propelled by the pinning action of the crushing grain.

Indexes to hardness were obtained by a hydraulic piston-regulated recorder unit which was driven by the outer wheel when it rotated. The hydraulic pressure was generated in a hydraulic cylinder, the plunger of which was actuated by the torque transmitted to the crusher frame by the crusher wheels. Either the number on the recorder or the hydraulic pressure, as registered on a pressure gauge, could be used as an index of hardness.

The coefficient of variability ranged between one and three per cent for tests on samples of corn.

BENNETT, EDMOND H.

Kernel hardness in corn.

II. A microscopic examination of hard and soft types of dent corn.

Cereal Chem. 1950, 27 (5) 232.

A close correlation was found between observed structure of the corn kernels and hardness as measured with the machine described in the foregoing article. Mature kernels of hard types of dent corn have smaller starch granules and more dense appearing protein matrix than softer types of dent corn. The amount of floury endosperm was found to be greater for the softer corns.

BILANSKI, W.K.

Breaking strength of seed grains.
Paper presented Annual Meeting of the Canadian Society of Agric. Engrs., Ottawa, June 1962.

Five common grains were tested under three different loading conditions and at various moisture contents. These three loading conditions closely simulate the three types to which grains are subjected during actual harvesting, and they were :-

(1) low-velocity loading, obtained by applying a load gradually;

(2) medium-velocity loading, obtained by striking the grain with a pendulum; and

(3) high-velocity loading, obtained by dropping the grain into the path of a rotating paddle which strikes it.

The size, moisture content, and position of the grain all influenced its breaking strength. As a rule under medium and high velocity loadings, more work was required to damage the grains having a high moisture content than those having a lower moisture content. Expenditure of a large amount of work to break a grain does not necessarily mean a high load as the grain might not be able to withstand deflection.

BRADBURY, DOROTHY et.al.

Conditioning wheat for milling.
Misc. Publ. No. 824, Agric. Res. Serv., USDA, May 1960.

Presented is a comprehensive survey of the literature concerned with the various methods for conditioning wheat in preparation for milling. Also included is data published on subjects related to wheat conditioning. This section covers the hygroscopicity of wheat, absorption and transmission of heat by wheat and the place of entrance and movement of water in the wheat kernel.

BROWNE, D.A.

Variation of the bulk density of cereals with moisture content.
J. Agric. Engng. Res. 1962, 7 (4) 288.

Curves showing the variation of bulk density with moisture content were obtained for rewetted samples of Atle, Cappelle, Dominator and Yeoman wheat, Plumage Archer and Proctor barley and Palu oats, over a moisture content range of 10 - 30% wet basis. Results for all the cereal varieties indicated a decrease in bulk density at higher moisture contents, but the rewetting process seemed to affect the results at the lower values.

BUELOW, F. H. & HALL, C.W.

Basic physical properties for materials handling design.
A.S.A.E. Paper No. 59-913, presented at 1959 Winter Meeting A.S.A.E., Chicago, Ill.

The need for research into physical properties of bulk handled materials is expressed. The following conclusions are put forward.

1. Data which are presented with test conditions completely defined and with the standard deviation give confidence and therefore are of much greater value and can be used more widely than most existing data.
2. Reliable data even with relatively large standard deviations, will make possible better engineering of materials handling equipment systems.
3. Because of the size of the testing program the co-operation of all researchers and a systematic and consistent approach is necessary for maximum result and benefit.
4. The most important physical properties for materials handling design should be investigated rather completely first. The way these basic properties vary with moisture content, pressure, product velocity, temperature and product variations should be determined.
5. With the consistent and concentrated approach on the determination of the basic properties, the engineering and design work for materials handling systems in agriculture will be greatly simplified and lead to better and lower cost systems for the farmer.

BURMISTROVA, M.F. & OTHERS.

Physicomechanical properties of agricultural crops.
Translated from Russian.
Book published for National Science Foundation,
Washington D.C., 1963.

This book, written collectively by a group of VISKHOM workers, contains the accumulated experimental results and standard programmes and methods used in investigations into the physicomechanical properties of agricultural plants. Data on size, weight, volume, and quantitative properties of plant and on strength indexes of various plant parts subjected to the actions of different machine working parts are presented. Data is also presented on friction coefficients of various plants subjected to different surface conditions, speeds, pressure, etc. The most important apparatuses used in studying the physicomechanical properties are also described.

FINNEY, E.E.

The viscoelastic behaviour of the potato, Solanum Tuberosum, under quasi-static loading.
Ph.D. thesis (Michigan) 1963 (unpublished).

Bruising during mechanical handling is a major problem in the potato industry. An investigation was conducted to obtain a more thorough understanding of the behaviour of the potato under the influence of externally applied non-impact forces. The potato was considered as a viscoelastic product.

Apparent elastic constants for potato tissue were determined by uniaxial compression tests and hydrostatic bulk modulus tests. Strength characteristics of the tuber were determined by loading a rigid die acting against the surface of the tuber with the skin intact. Effects of rates of deformation, tuber temperature and traction areas upon the strength of the tuber were determined.

The potato, similar to other viscoelastic materials, exhibits stress relaxation which can be represented qualitatively by a Maxwell model. Stress relaxation within the potato tuber was represented by four parallel Maxwell models having time-constants in the form of a geometric progression.

FINNEY, E.E.; HALL, C.W.; MASE, G.E.

Theory of linear viscoelasticity applied to the potato.
J. Agric. Engng. Res. 1964, 9 (4) 307.

A physical basis was established for considering that the potato tuber behaves as a viscoelastic body when deformed by mechanical loading. An analysis of the primary elements in viscoelastic models is presented.

The potato tuber exhibited a time dependent property characteristic of most viscoelastic high polymers, namely, stress relaxation. The rate of mechanical loading had a significant influence upon the relaxation process. After 5 sec. the relaxation time was relatively unaffected by the rate of loading.

Graphical, inflection and geometric series methods of representing characteristic time constants were investigated. Stress relaxation within the tuber was represented qualitatively by the equivalent response of 4 Maxwell models in parallel. Each model had characteristic time constants of 1, 10^2, 10^4, 10^8 sec. respectively. With the large time constants in the relaxation function, it was apparent that the rate of dissipation energy within the material was small compared to the mechanical energy stored.

GROSH, GORDON M. & MILNER, MAX.

Water penetration and internal cracking in tempered wheat grains.
Cereal Chem. 1959, 36, 260.

Studies of water penetration in wheat grains, carried out by means of X-ray and a novel freeze-sectioning technique which does not affect the moisture status and physical structure of the kernels, revealed that cracks, radial and transverse to the crease, occur in hard vitreous endosperm in advance of water movement through the kernels. These cracks are most noticeable at moisture levels in the range employed in commercial tempering operations.

Peripheral absorption of water creates stresses between wet and dry portions which cause radial and transverse cracks that provide pathways for further penetration of water. These fractures eventually facilitate the formation of middlings during milling. The cracking phenomena is not observed in non-vitreous wheats.

HALL, C.W.

Drying farm crops.
Book published by Agricultural Consulting Associates, Inc., 1957.

In recent years considerable research has been reported in separate articles concerning the drying and storing of farm crops. The author has attempted to place the most important of these items, containing both theoretical and practical considerations under one cover.

Major emphasis is placed on the common cereal grains and hay. Topics relating to a successful drying programme, such as moisture movement, measurement of moisture content, storage and handling are covered.

<u>KATZ, R; CARDWELL, A.B.; COLLINS, N.D.; HOSTETTER, A.E.</u>

A new grain hardness tester.
Cereal Chem. 1959, 36 (5) 393.

A hardness tester, especially adapted for grain, was constructed by modifying a commercial portable soft metal tester known as the Barcol Impressor. A preloaded stylus is forced into grain sections prepared by means of a microtome. The displacement of the stylus, measured by a dial micrometer, is used as a hardness index. This has been related to the Vickers diamond pyramid hardness which is a standard metallurgical test. A number of hardness measurements may be made on a single transverse kernel section. The tester may be used for all wheat varieties. Significant variations in hardness within a single wheat kernel have been demonstrated. While the hardness of a block of lead varied over $\pm \frac{1}{2}$ hardness number, a kernel section of hard winter (Ponca) wheat exhibited hardness numbers ranging from 25 to 40, on the arbitrary scale of this tester.

KRAMER, HAROLD A.

Physical Dimensions of Rice.
Agric. Engng. 1951, 32, (10) 544.

A study of rice seed dimensions was conducted using samples of 35 varieties harvested from the 1949 field plot variety test at the Rice Pasture Experiment Station, Beaumont, Texas, and one sample of red rice. Measurements of length, width, and thickness with and without the husk are presented together with the coefficient of variability.

The reader is cautioned to remember that the data is based on varieties grown during one season at one location. It is not known what effect differences in fertility, soil type, irrigation, climate and other factors, may have on the average dimensions and uniformity of a variety.

LORENZEN, ROBERT T.

The effect of moisture on weight-volume relationships of small grain.
A.S.A.E. paper 58-111. - Presented at the 51st annual convention of the A.S.A.E., Santa Barbara, Calif., June, 1958.

Moisture effect on friction coefficients of small grain.
A.S.A.E. paper 59-416 - presented at annual meeting of A.S.A.E., Ithaca, N.Y., June, 1959.

These papers formed part of a master's thesis entitled "Effect of moisture content on mechanical properties of small grain" written at the Agric. Engng. Dept., Univ. of Calif., Davis.

In the first paper the author presents the physical aspects of the two marketing units hundred-weight and bushel so that their relative merits may be compared.

Special emphasis is made regarding the effect of moisture variations on these units. Physical factors such as specific weight, total volume, volume of solids and true specific gravity are studied to ascertain the affect of variations on the grain marketing units.

The research reported in the second paper is a study in which the moisture content of the grain is isolated as a possible variant which could account for the wide range of reported values of friction coefficient for a particular material. The author concludes that there are three possible variants which may have played a part in determining the values of coefficients of friction in former studies. These variants are grain moisture content, pressure of grain on the friction surface, and condition of the friction surface.

McCLUGGAGE, M.E.

Factors influencing the pearling test for kernel hardness in wheat.
Cereal Chem. 1943, 20, 686.

Tests were performed on a Strong-Scott barley pearler, model 38, to assess the influence of the following factors on the pearling test for kernel hardness in wheat

(a) temperature of the wheat and the pearler,
(b) sifting of the pearled wheat,
(c) speed of the grinding wheel and the length of the pearling time,
(d) size of the change,
(e) the screen used in the pearler,
(f) moisture content of the wheat.

The reliability of the pearling test was shown by comparing the results obtained in different laboratories on check samples.

There is also a presentation of an accumulation of data on kernel hardness for varieties of hard red winter wheat grown in the southern Great Plains in 1938, 1939 and 1940.

MILNER, MAX; SHELLENBERGER, J.A.

Physical properties of weathered wheat in relation to internal fissuring detected radiographically.
Cereal Chem. 1953, 30, 202.

The reduction in density of wheat caused by natural weathering or by wetting and drying in the laboratory is due to the formation of internal fissures which can be detected radiographically. These fissures appear when moisture-swollen grain is dried in a manner which will produce stresses within the wheat kernel. Rapid drying of immature grain of high moisture content does not produce fissuring, but such dried grain when rewetted and redried fissures readily, indicating a fundamental change in structure of the endosperm constituents with maturation.

Wheat hardness and the energy requirement for grinding are both reduced when grain becomes weathered and internally fissured. The rate of absorption of water is increased also. The practical inferences of these findings are discussed.

MITCHELL, F.S.; ROUNTHWAITE, T.E.

Resistance of two varieties of wheat to mechanical damage by impact.
J. Agric. Engng. Res. 1964, 9 (4) 303.

As the threshing of grain from an ear of wheat takes place largely by the impact of the beater bar on the ear, it was considered desirable to have some knowledge of the impact that an individual grain could withstand without becoming damaged. The results obtained from striking individual grains with a rotating hammer confirmed earlier work* that whereas Koga II wheat is more resistant to breakage than Cappelle Desprez, it is at the lower levels of moisture that breakage is highest and at the higher levels of moisture that germination is most adversely affected. Even the lower speed of 3,280 ft./min. had a small adverse affect on germination, while at about 7,000 ft./min. only about one third of the grains remained undamaged. The percentage of undamaged grains was shown to be related to the square of the peripheral speed of the hammer.

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* MITCHELL, F.S. The effect of drum settings and crop moisture content on the germination of combine harvested wheat.

Reg. 51. Nat. Inst. Agric. Engng, Silsoe, 1955.

MOHSENIN, N.N.

Physical properties of agricultural products - A new challenge for agricultural engineers.
Papers presented A.S.A.E. Winter Meeting, Chicago, 1963.
Also, Trans A.S.A.E. 1965, 8 (1) 25.

A general paper in which the author discusses briefly the importance of the engineering properties of agricultural products, the need for study and research and the opportunity that is one of the most exciting and challenging insofar as agricultural engineers' contribution to the vast and growing area of the science of materials is concerned.

The properties discussed are presented under the following categories :

physical characteristics
aero and hydrodynamic characteristics
electrical properties
light transmittance and light reflectance characteristics
thermal properties
mechanical and rheological properties.

An extensive list of references is cited at the end of the paper.

MOHSENIN, N.N.

A testing machine for determination of mechanical and rheological properties of agricultural products. Bulletin 701, Penna. Agr. Exp. Sta., 1963.

A pneumatic machine with strain gauge or transducer, force and deformation measuring devices has been developed to study the mechanical and rheological properties of agricultural products.

Several examples are presented to illustrate the application of this machine in determining certain properties of fruits, vegetables, grains and forage materials.

MOHSENIN, N. N. & GOHLICH, H.

Techniques for determination of mechanical properties of fruits and vegetables as related to design and development of harvesting and processing machinery.

J. Agric. Engng. Res. 1962, 7 (4) 300.

New techniques, apparatus and instrumentation are presented which were developed for studying the mechanical behaviour of fresh fruits and vegetables when they are subjected to such mechanical treatments as compression under increasing load, compression under static load, impact loading, and shearing and puncturing forces. Determination of stress, deformation and energy required to begin flesh discoloration and damage immediately below the skin was the primary concern. Apple was used as a testing material, but the techniques and instrumentations can be adapted to many other products.

The precision and the slow rate of loadings of the compression testing apparatus developed in this work were such that, in addition to a rupture point, a yield point was detected in the stress-deformation curves of the product. The stress, deformation and energy at this yield point corresponded to the beginning of bruising and discoloration of fruit tissues under the skin. It was also found that the energy corresponding to the point of skin rupture could be taken as a safe measure of skin toughness and skin resistance to puncturing and shearing forces. The hysteresis loops, produced by the x-y recorders of the compression testing machine, indicated the ability of the fruit to absorb or store energy without being deformed beyond the yield point or bruising. The recovered energy, indicated by the hysteresis curves, can be taken as the energy capacity of the fruit.

On the basis of the data obtained in this investigation, it appears that the results of the compression testing machine can be used to predict the force and energy which would cause the beginning of bruising by dead load compression and impact loading, respectively.

MOHSENIN, N.N.; GOCHLICH, H.; TUKEY, L.D.

Mechanical behaviour of apple fruits as related to bruising.
Am. Soc. Hort. Engrs. 1962, 81, 67.

Apparatus same as described in Bull. 701.

Results similar to those described in previous paper.

MOHSENIN, N.N.; COOPER, H.E.; TUKEY, L.D.

Engineering approach to evaluating textural factors in fruits and vegetables.
Trans. A.S.A.E. 1963, 6 (2) 85.

Machine used as in Bull. 701.

Tests and results as in previous papers.

In addition a mechanical analogy and the associated rheological equation is proposed for distortion of products under dead load. The Maxwell, Kelvin and Burgers models are discussed in an endeavour to help understand the "why" of mechanical behaviour.

NELSON, S.O.; SODERHOLM, L.H.; YUNG, F.D.

Determining the dielectric properties of grain.
Agric. Engng. 1953, 34 (9) 608.

The Boonton Q-meter equipped with a newly designed co-axial cylindrical test-condenser has been used successfully for determining the dielectric properties of grain in the frequency range from 1 to 50 megacycles. The advantages of this method include the reduction of inaccuracies due to residual and lead inductances through utilization of the reactance-variation method of measurement and provision for measurement of the electrical properties of benzene or other standard liquids by which the accuracy of determinations may be checked. A detailed description of the test condenser and a brief explanation of the method are presented.

Formulas are given for the calculation of dielectric properties from electrical measurements. Tests using benzene as a standard material indicate that the method permits accurate measurements of the electrical properties in the frequency range from 1 to 50 megacycles. Values of dielectric constant, loss tangent, loss factor and conductivity in this frequency range are shown as obtained from a typical test made on a sample of barley.

PARKE, D.

The resistance of potatoes to mechanical damage caused by impact loading.
J. Agric. Engng. Res. 1963, 8 (2) 173.

The effect of impact forces upon potato tubers was investigated, the impact being delivered by a heavy pendulum, and the energy absorbed by the potato calculated. Damage was assessed in terms of the numbers of tubers split and bruised and the volume of tissue bruised.

PERRY, J.S.; HALL, C.W.

Germination of pea beans as affected by moisture and temperature at impact loading.
Quart. Bull., Mich. Agric. Exp. Sta. 1960, 40 (1) 33.

Selected pea beans were dropped from a height of $22\frac{1}{2}$ ft. through a 4" diameter tube onto other beans at about 18% m.c. (w.b.). Moisture contents ranged from 12 to 18% m.c. (w.b.) and temperatures used were 40°F and 50°F.

The beans were examined for visibly damaged seed coats, reduction in germination and reduction in normal plants with no defects.

PERRY, J.S.; HALL, C.W.

Evaluating and reducing mechanical handling damage to pea beans.
A.S.A.E. Paper No. 60-807. Presented at A.S.A.E. Winter Meeting, Memphis, Tennessee, December 1960.

As well as the dropping procedure as described in the previous paper, a spring-loaded striking bar was used to impact pea beans of 8.2 to 17.8% m.c. (w.b.) at velocities corresponding to a 20 to 25 ft. fall. A high speed movie camera was used to obtain information about these impacts.

REHKRUGLER, G.E.

Modulus of elasticity and ultimate strength of the hen's egg shell.
J. Agric. Engng. Res. 1963, 8 (4) 352.

A technique for determining the elastic modulus and tensile and compressive stress in an egg shell failure was established.

Tests were conducted and evaluated to produce representative values of egg shell material strength. The values indicated are not to be considered exact measurements of egg shell strength, but are intended to indicate the order of magnitude of the material strength.

Results of the strength test compare favourably with those for the chemically similar material, limestone.

ROBERTS, H.F.

A quantitative method for the determination of hardness in wheat.

Kans. Agr. Expt. Sta. Bul. 167, 1910, 371.

Presented is an account of an apparatus designed to determine qualitatively, in terms of the mean crushing-point of the kernel, different degrees of hardness in wheat; this factor, or rather combination of factors, being considered indicative of superior milling quality in wheat.

SHPOLYANSKAYA, A.L.

(Structural-mechanical properties of the wheat grain.)
Kolloid, Zh.; 1952, 14 (1) 137.

Methods are proposed for the determination of quantitative characteristics of a series of structural-mechanical properties of cereal grains using a laboratory impact tester with static compression. Certain of the mechanical property characteristics are conventional and their dimensions are not quite usual as a result of the fact that the grain is a body of complex configuration and strain is distributed irregularly in it.

The investigations have shown that the cereal grain, being an elastic-plastic-viscous body, possesses elasticity, plasticity and viscosity; it exhibits creep with a constant velocity, relaxation of stresses and elastic after-effects. A model of the mechanical properties of the grain has been proposed.

An expression for the modulus of elasticity of a grain using the simplified Hertz formula for the compression of two spheres, has been proposed.

SWANSON, C.O.

Effects of moisture on the physical and other properties of wheat.
Cereal Chem. 1941, 18, 705.

Evidence is presented to show that wetting wheat, either before or after threshing, lowers the test weight and decreases the vitreous condition. Since test weight and vitreous appearance (in contrast with bleached and mealy appearance) are two important factors in grain grading, exposure to rain during harvest seriously affects the grade. The decrease in test weight, however, did not produce correspondingly lower flour yields. The baking values also did not correlate with the commercial grade nor with the extent of the wetting treatment. An explanation is given of the physical changes that take place.

SWANSON, C.O.

Effect of moisture on the physical and other properties of wheat. II. Wetting during harvest. Cereal Chem. 1943, 20, 43.

Studied are the effects of wetting during harvest on grain grades, test weights, internal textures, and milling and baking values.

Conclusions similar to the previous paper are presented.

Effect of moisture on the physical and other properties of wheat. III. Degree, duration and number of wetting treatments.
Cereal Chem. 1943, 20, 286.

Effect of moisture on the physical and other properties of wheat. IV. Exposure of five varieties to light rains during harvest.
Cereal Chem. 1943, 20, 703.

These two articles are continuations of the previous work. The properties examined for the conditions mentioned in the titles are as indicated above.

SYMES, K.J.

Classification of Australian wheat varieties, based on the granularity of their wholemeal.
Aust. J. of Exp. Agric. and Animal Husb. 1961, 1, 18.

A simple and accurate test for determining the granularity of wheat wholemeal is described. Ten grams of wheat are ground, sieved for five minutes and the amount passing through the sieve is expressed as a percentage of the original sample and recorded as the particle size index.

Particle size index is shown to be a varietal character that divides Australian varieties into two distinct groups. As all typical hard varieties fall into one of these groups and all typical soft varieties into the other group, particle size index is suggested as the most satisfactory criterion for designating these categories.

Variations in protein level and moisture content do influence the particle size index, without in any way invalidating the test. The effect of changes in these environmental factors, on particle size index, varies from variety to variety both in degree and direction.

SYMES, K.J.

The inheritance of grain hardness in wheat as measured by the particle size index.
Aust. J. Agric. Res., 1965, 16, 113.

The difference in particle size index between a hard wheat (Falcon) and a soft wheat (Heron) is shown to be due to a single major gene. Tests of F_2 populations of seven other crosses between hard and soft wheats indicate that this is not uncommon.

The existence of minor genes which modify the action of the major gene in determining the hardness or softness of wheat grain is also demonstrated. In at least one case (Spica) a different level of hardness appears to be due to a different major gene from that found in Falcon and not to modifying genes.

The conversion of a hard wheat to a soft wheat or vice versa can be achieved by back crossing. The grain hardness of the new wheat will be influenced both by the hardness of the donor parent and by the degree to which modifying genes are carried over.

This demonstration of the simple inheritance of grain hardness as measured by particle size index is of significance to wheat improvement programmes.

<u>TAYLOR, J.W.; BAYLES, B.B.; COLBURN, C.F.</u>

A simple measure of kernel hardness in wheat.
J. Am. Soc. Agron. 1939, 31, 775.

A simple pearling test for measuring the hardness of wheat kernels is described. The test is economical with respect to equipment, time, and quantity of grain.

The results are consistent with what is known regarding the relative hardness of wheat of different varieties and very high interstation correlations were obtained.

High correlation coefficients were found between the percentage of the kernels pearled off and the particle size index. Only slightly lower negative correlation coefficients were obtained between the percentage of kernels pearled off and the doughball time. Little correlation was found between the percentage pearled off, particle size index, doughball time, and protein content of the grain of the varieties studied.

TIMBERS, G.E.; STALEY, L.M.; WATSON, E.L.

Determining modulus of elasticity in agricultural products by loaded plungers.
Agric. Engng. 1965, 46 (5) 274.

The modulus of elasticity for a materials is obtained by utilizing the Boussinesq solution for the stress distribution under a rigid die (or plunger). To use the method it is necessary to have a value for Poisson's ratio.

Results are presented for potato tubers. These results show some variation with the diameter of the plunger used but this variation is much less obvious than previous methods which have been used.

ZINK, F.J.

Specific gravity and air space of grains and seeds.
Agric. Engng. 1935, 16 (11) 439.

Data concerning the specific gravity, density and void space for several grain types is presented.

<u>ZOERB, G.C.; HALL, C.W.</u>

Some mechanical and rheological properties of grains. J. Agric. Engng. Res. 1960, 5 (1) 83.

also

<u>ZOERB, G.C.</u>

Mechanical and rheological properties of grain. Ph.D. Thesis (Michigan) 1958 (unpublished).

Basic mechanical and rheological properties of individual bean, maize and wheat kernels were determined. Moisture content had the greatest influence on the strength properties of the grain. The compressive strength, modulus of elasticity, maximum compressive stress, and shear stress generally decreased in magnitude with an increase in moisture content. Energy requirements for impact shear was higher than static shear at a high moisture content but the modulus of resilience and modulus of toughness did not vary greatly.

Stress relaxation with time was studied for three moisture levels and three deformation rates. Initial rate of deformation had more effect on the rate of stress relaxation than moisture content or the initial amount of deformation. A two-term exponential equation was obtained graphically to express the stress/relaxation/time relationship.

APPENDIX 4.

NOTES ON SOME OF THE VARIETIES TESTED

Bordan was selected from the cross (Bearded Reiti x Ford) x Dan made at Roseworthy Agricultural College, South Australia and released in 1924.

It is recommended for early sowing in the better rainfall districts. It is tall growing with straw of fair strength and grain of medium strength. It is a recommended variety in N.S.W. in 1966.

Chile 1B imported as a commercial variety from South America. It is semi-dwarf in character and has very poor baking qualities. It is being used in breeding programmes but has not been released in Australia.

Dural was selected from the cross Aleppo x Palestine. It was selected for the production of high quality macaroni-type semolinas. The grain is white and vitreous. The straw of medium height and strength. It is a recommended variety in N.S.W. in 1966.

Falcon was bred and selected at Temora Agricultural Research Station from the cross Gular x (Dundee x Gular) x Bencubbin. Falcon is classed as a hard wheat, both from the point of view of appearance and physical hardness as it affects milling. Straw is medium tall and of moderate strength. Grain is white and vitreous. A recommended variety in N.S.W. in 1966.

<u>Festiguay</u> was selected at Tamworth Agricultural Research Station from the cross Festival x Uruguay made at Glen Innes Agricultural Research Station. Straw is fine and slender and of moderate strength. Grain is hard and has good bushel weight. It has good baking quality, especially at high protein levels. It is a recommended variety in N.S.W. in 1966.

<u>Gabo</u> was bred at Sydney University from a Bobin selection x Gaza and Bobin selection. It was the leading variety in the State in 1956 to 1958, but it is no longer recommended. Straw is of moderate strength. Grain threshes easily but has shown a tendency to shatter. Bushel weight is relatively low; has excellent baking qualities.

<u>Gala</u> is a popular variety in Queensland but has not been recommended in N.S.W. because of its low yield; is an excellent bread wheat.

<u>Gamenya</u> was selected from the cross Gabo x ((Gabo^5 x Mentana) x Gabo^2 x Kenya 117A). The grain resembles Gabo in many respects. It has excellent baking qualities and is the highest yielding variety at present grown in northern areas. It is a recommended variety in N.S.W. in 1966.

<u>Glenwari</u> was produced by the Waite Research Institute, South Australia, from the cross Nabawa x (Riverina x Hope), released in 1948. Gives a good yield but has never been a recommended variety in N.S.W. due to its poor baking quality. However, it was the leading variety in the State from 1959 to 1962.

Heron was selected from the cross R.D.R. x 4 Insignia 49 and released by the Wagga Agricultural Research Institute. It has short, strong straw and stands well. The grain is easy to thresh; baking quality is in the soft wheat class. Heron is the highest yielding early maturing variety in the central and southern areas of the State and was the most popular variety in the State in 1963 and 1964. It is a recommended variety in 1966.

Mendos was bred at Sydney University from the cross ((Spica x Koda) x Gabo) x Mengavi sib. It has excellent milling and baking qualities. It is a recommended variety in N.S.W. in 1966.

Mengavi was selected from the cross ($Gabo^6$ x Mentana) x ($Gabo^2$ x (Eureka x C.I. 126321)). Grain has similar baking qualities to Gabo.

Mexico 120 - remarks similar to Chile 1B apply.

Pinnacle was the result of a selection from Pindar, made by the Victorian Department of Agriculture and released in 1946. It is a late maturing wheat with short, strong straw; baking quality is in the soft wheat class. It is a recommended variety in N.S.W. in 1966.

Spica was bred in 1934 by Queensland Department of Agriculture from a cross (Three Seas x Kamburico) x (Pusa x Flora 3202); released in 1952. It is a particularly free milling wheat. It has been classed as strong in its baking quality under older baking methods, but is now suspect in the automated bakehouse. It is a recommended variety in N.S.W. in 1966.

<u>Windebri</u> is a winter wheat with tall straw of moderate strength; grain is strong in baking quality. It is a recommended variety in N.S.W. in 1966.

Generally, these notes have been extracted from references (38, 39, 40).

APPENDIX 5.

METHOD FOR THE DETERMINATION OF SYMES' PARTICLE SIZE INDEX.

A 10 grain sample of wheat is ground in a Labconco mill set to grind as finely as possible. The mill is fitted with a gravity feed, consisting of a funnel and a 5 inch length of $\frac{7}{8}$ inch diameter pipe, to ensure a uniform rate of grinding. The meal is sieved through 200 mesh brass cloth (opening 74 μ), in half height, 8 inch diameter Tyler sieves, each with its own cover and bottom pan. Six such units are placed on a Ro-tap sieve shaker for 10 minutes, whole wheat being placed on the sieve with the meal, to prevent clogging the sieve. The material passing through the sieve is weighed to the nearest 0.01 grain and, expressed as a percentage, is called the particle size index. With this technique the coefficient of variation of a control sample over a period of several months was 2.3%.

APPENDIX 6.

TYPICAL COMPUTER OUTPUT FOR ANALYSIS OF INDIVIDUAL SAMPLES.

VARIETY NUMBER 6510.

MOISTURE CONTENT 11.5

Flat Position - Proportional Limit Load.

TEST No.	SIZE in.	LOAD lb.	DEFORM in.	INDEX lb.
1	0.1299	14.2	0.00533	345.62
2	0.1260	9.9	0.00430	290.03
3	0.1339	13.1	0.00512	343.53
4	0.1260	13.2	0.00880	188.81
5	0.1299	16.1	0.00706	295.59
6	0.1260	15.4	0.00442	439.29
7	0.1339	9.5	0.00421	302.42
8	0.1260	18.0	0.00809	280.21
9	0.1260	15.4	0.00558	347.25
10	0.1299	12.7	0.00516	319.35

	MEAN	STD. DEV.	STD. DEV. %
LOAD	13.74	2.660	19.35
INDEX	315.21	63.726	20.22

NOTE : Similar output was also obtained for the flat position, maximum load; edge position, proportional limit and maximum loads.